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Regulation, Innovation, and Market Structure in the U.S. Pesticide Industry

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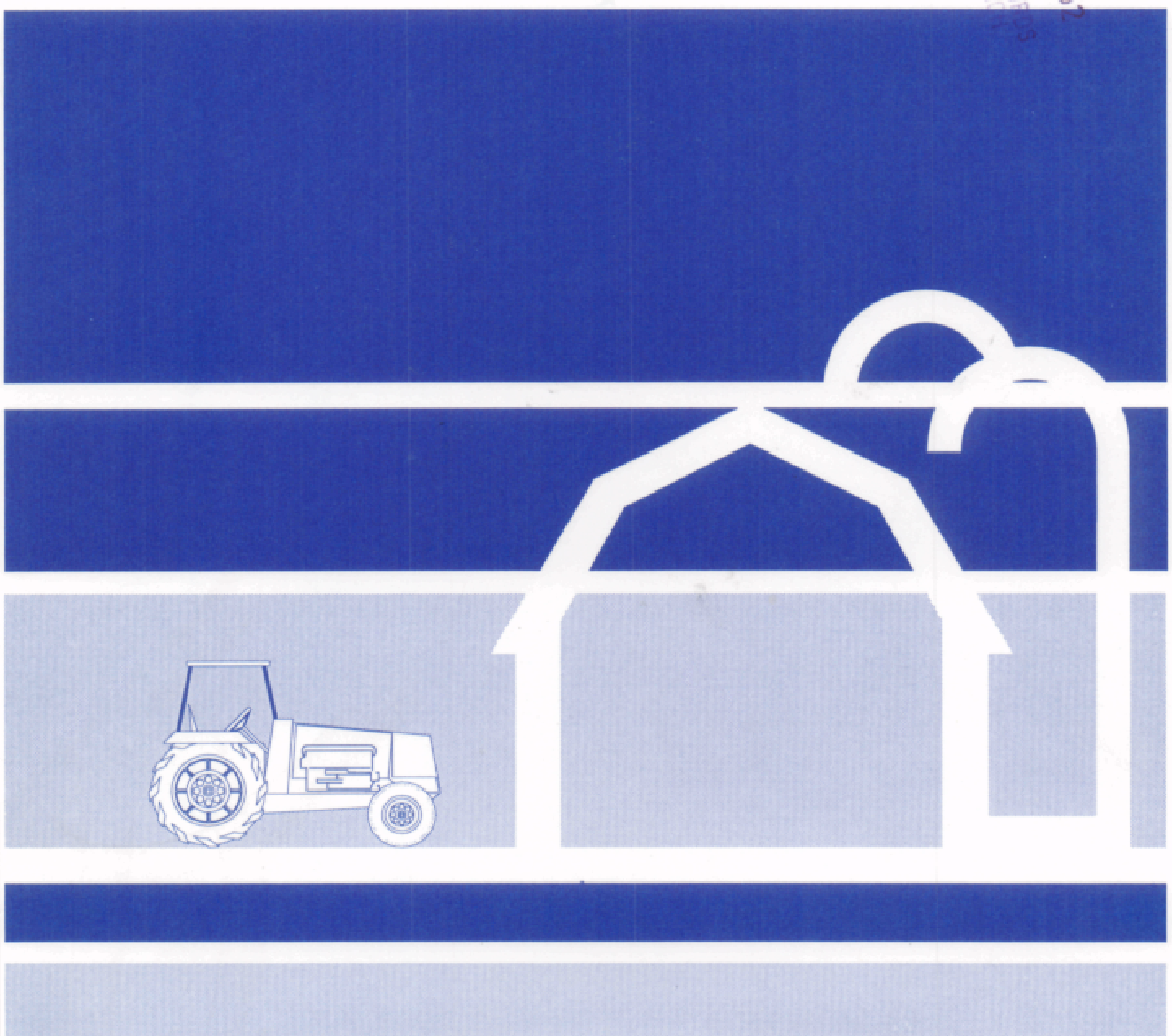

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Abstract

Pesticide regulation encourages the development of "less toxic" pesticides but discourages new chemical pesticide registrations, increases the market size for new pesticides, and encourages chemical pesticide firms to abandon minor crop markets. Pesticide regulation also favors large firms over small ones and encourages firms to develop nonchemical alternatives to chemical pesticides.

Keywords: Pesticides, regulation, toxicity, innovation, market structure

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Summary

Pesticide regulation in the United States has encouraged fewer, yet less toxic, new chemical pesticides. The number of new chemical pesticides registered by the EPA dropped by 49 percent between the 1972-76 and 1987-91 periods, and those with chronic health effects dropped by 86 percent between the 1972-76 and 1985-89 periods. The findings of this study suggest that pesticide regulations have encouraged firms to focus their chemical pesticide research on pesticides for larger crop markets and abandon pesticide development for smaller crop markets.

Concern over the health and environmental effects of chemical pesticide use caused Congress to enact major amendments to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) in 1972, 1978, and 1988. These amendments required that new and existing pesticides meet strict health and environmental standards. As a result, pesticide companies have refocused their research on pesticides that degrade rapidly and have stopped developing pesticides that persist in the environment. The low-toxicity pesticides now account for more than half of sales of new pesticides.

The findings of this study also suggest that EPA chemical pesticide regulation has indirectly affected the number and type of pesticide firms. Each 10-percent increase in new pesticide regulatory costs causes a 2.7-percent reduction in the number of new pesticides. Higher regulatory costs contributed to an industry-wide increase in research spending. This increase encouraged some small firms (companies with sales below the industry average) to leave the chemical pesticide industry. Although the exit of some companies has reduced the potential for greater innovation, the firms that remain are those better able to exist in a more stringent regulatory environment and, perhaps, more likely to develop less toxic pesticides.

The decline in new registrations of chemical pesticides for smaller crop markets suggests that market opportunities exist for biological pesticides and genetically modified plants. Biological pesticides (viruses, parasitic and pathogenic bacteria, and predators) are environmentally appealing because they occur naturally. Also, there is evidence that the cost of developing and registering a biological pesticide is less than that of registering a chemical pesticide. However, they currently have only a small share of the total pesticide market because they are ineffective on crops affected by numerous pests. Genetically modified plants with pest-resistant characteristics are also environmentally appealing. However, like biological pesticides, they are effective against only a narrow range of pests, and, thus, have a limited potential to displace chemical pesticides.

Regulation, Innovation, and Market Structure in the U.S. Pesticide Industry[1]

Michael Ollinger
Jorge Fernandez-Cornejo

Introduction

In 1992 U.S. farmers spent almost $6 billion on chemical pesticides to control pests (National Agricultural Chemicals Association—NACA). Chemical pesticides have played a major role in increasing farm productivity (Headley, 1968; Campbell, 1976). For example, corn yields rose threefold over the past 40 years, enabling 10 percent less land to produce more corn. Despite the positive effect of chemical pesticides on agricultural productivity, there is concern about their use among some consumers and experts who follow the industry. Harper and Zilberman (1989), many other economists, and some consumers believe that pesticides cause risks to farmworkers, contaminate ground and surface water, have harmful effects on wildlife, and, because of residues, cause health risks to consumers. Hence, pesticides have been instrumental for high agricultural productivity but have potentially harmful side effects. These potential side effects have prompted the U.S. Government to strictly regulate the introduction of new chemical pesticides.

Amendments enacted in 1972, 1978, and 1988 to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) increased the regulatory stringency of the existing FIFRA legislation. The amendments required new and existing pesticides to meet strict health and environmental standards. Critics of Environmental Protection Agency (EPA) regulatory enforcement of FIFRA, such as Hatch (1982), assert that the cost of complying with pesticide regulations reduces the incentive to develop new pesticides by making it unprofitable to develop chemical pesticides for crops not likely to generate high revenues, such as many fruits and vegetables.[2] Other critics provide anecdotal evidence that regulatory costs have deterred firms from registering pesticides for minor crops and thus may cause a reduction in the pest management alternatives available to producers (Giannesi and Puffer, 1992). Additionally, some researchers question whether more stringent regulations result in safer pesticides (Lichtenberg, Spear, and Zilberman, 1993).

Greene, Hartley, and West (1977) hypothesize that high regulatory costs reduce the incentive to develop pesticides for smaller crop markets and encourage firms to develop pesticides that are effective against many types of pests and under diverse weather conditions. However, the need to make these wide-spectrum pesticides effective under diverse conditions may have undesirable side effects because they must be highly toxic to many types of pests and thus are more likely to be highly toxic to humans and fish and wildlife.

Previous research indicates that Food and Drug Administration (FDA) and Occupation Safety and Health Administration regulations affect producers and workers. Thomas (1990), for example, showed that pharmaceutical regulation affects small companies more than large companies. Other economists concluded that safety and health regulation favors union workers over non-union ones and heavy industry over light industry (Pashigian, 1984; Bartel and Thomas, 1987).

This report examines how EPA regulation affects new chemical pesticide registrations, new chemical pesti-

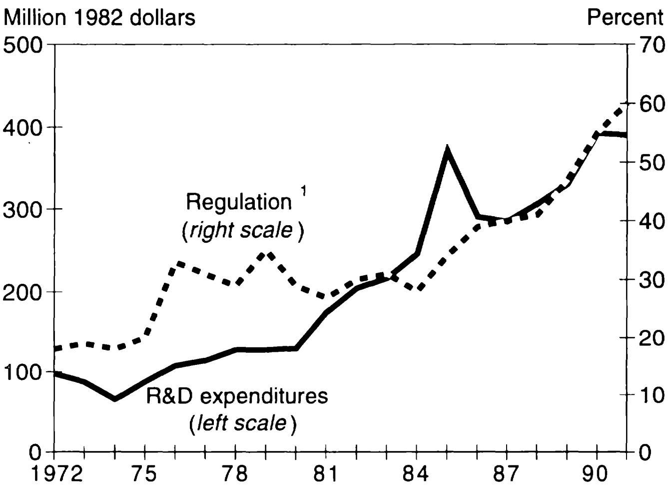
[1]In this report, innovation means the registration of a new chemical active ingredient to be used as a pesticide.

[2]The introduction of new pesticides is important because pests develop resistances to pesticides, making old pesticides less effective as pest control agents. Farmers fear that a decline in pesticide effectiveness will increase crop damage attributed to pests. For the consumer, more crop damage would mean higher prices for farm products.

cide safety, new chemical pesticide use, industry composition, and technology choice. Between 1972 and 1989, private agricultural research expenditures used for toxicological and environmental testing (testing costs) rose from 14 to 47 percent of total pesticide research spending, and pesticide development time rose from 7 to 11 years (fig. 1). Meanwhile, the number of new pesticide registrations fell from 46 over the 1972-76 period to 24 over the 1987-91 period. Potential health effects of new pesticides improved, with only 3 percent of those registered over the 1985-89 period having chronic health effects versus 13 percent over the 1972-76 period (fig. 2). In terms of markets served, the number of new pesticide registrations for vegetables, fruits, and nuts declined from 62 over the 1972-76 period to 15 for 1985-89, while registrations for major crops (corn, soybeans, wheat, cotton, and sorghum) remained almost unchanged (fig 3).

Historical data suggest that a linkage may exist between regulation and market structure. As the costs of toxicological and environmental testing rose over the 1972-89 period, the number of companies developing new pesticides through agricultural research (innovative pesticide companies) dropped from 33 to 19, and the U.S. market share held by foreign-based companies rose from 18 percent to 43 percent (fig. 4). Much of the structural change came as major domestic pesticide companies sold their operations to larger foreign-based international companies. Firms with sales below the industry median were even more affected, dropping from 16 in 1972 to 6 in 1989 (fig. 4).

Figure 1
Research spending and pesticide regulation

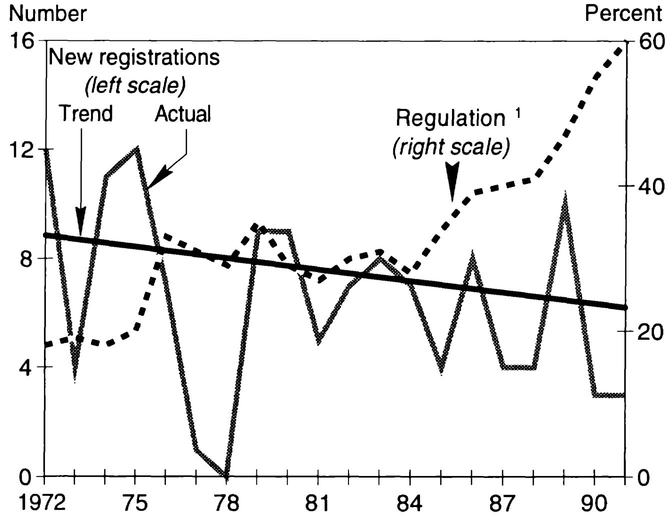


[1]Regulatory R&D costs as a percentage of total R&D costs. These include the costs of environmental testing, mammalian toxicity studies, and EPA registration costs.

Causes of Changes in New Pesticide Innovation and Industry Composition

A number of factors including research and development expenditures, regulatory costs, and the health of the farm economy affect the development of new pesticides. No factor that a firm can control is more important than research. By changing its research expenditures, a firm can influence the rate at which it introduces new pesticides. For example, a company

Figure 2
New pesticide registrations and regulation



[1]Regulatory R&D costs as a percentage of total R&D costs.

Figure 3
Number of pesticides registered for fruits and vegetables

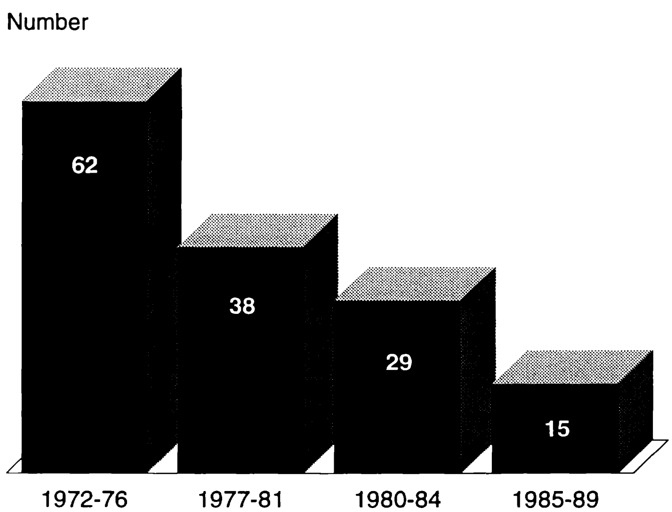
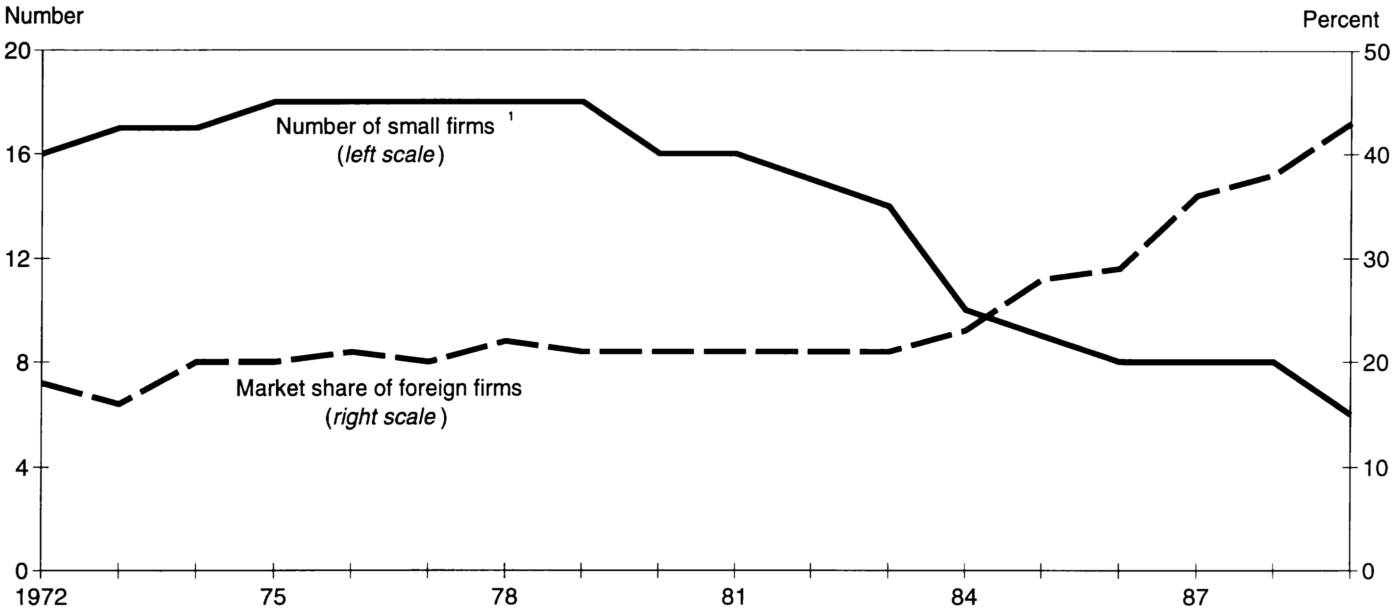


Figure 4
Number of small pesticide firms in United States and U.S. market share of foreign-based firms



[1] Firms below the median sales level in 1972. Sales are estimated world sales.

may double its expenditures and increase new pesticide introductions or make no investment and stop developing new pesticides.

Regulation, Industry Growth Cycle, and Farm Economy Changes

Regulation of new pharmaceutical introductions is comparable to pesticide regulation because in both cases a regulatory regime demands extensive testing prior to granting a registration. Economic research of FDA regulation may thus have implications for the pesticide industry. Some studies of pharmaceutical innovation show that FDA regulation reduced new pharmaceutical registrations (Peltzman, 1973; Grabowski, Vernon, and Thomas, 1978; Thomas, 1990). Thomas (1990) attributes most of the decline to a drop in new registrations of close substitutes to existing drugs. These pharmaceuticals have a smaller market size than novel pharmaceuticals and are usually introduced by small companies.

A 1981 study notes that an increase in regulatory stringency from 1968 to 1978 corresponded with an increase in the direct costs of bringing a pesticide to market; a rise in the time required to take a pesticide from discovery to registration; and a shift in research expenditures from synthesis, sçreening, and field testing to registration, toxicological and environmental testing, and residue analysis (Council for Agricultural Science and Technology—CAST). Another 1981 report shows that the rise in new research from 1968 to 1978 did not cause an increase in new pesticide registrations (Office of Technology Assessment—OTA). Hatch (1982) estimated that the increase in the time required to bring a new pesticide to market resulted in a 7- to 9-percent decrease in pesticides registered.

Greene, Hartley, and West (1977) argue that regulatory-related testing costs are independent of the size of the crop market. Potential revenues from crop markets vary, however. Consequently, pesticide development is profitable only if a pesticide is effective on at least one major crop market, such as corn or soybeans, and many minor ones, such as fruits and vegetables. They add that these wide-spectrum (multiple-use) pesticides are more likely to have undesirable health and environmental side effects than single-use pesticides because they must be effective against numerous pests and under diverse weather conditions.

Pashigian (1984) and Bartel and Thomas (1987) shed some light on how regulation affects firms. They found that regulation causes an increase in the minimum competitive firm size and thus benefits large firms at the expense of small companies. Thomas (1990) suggests that regulation favors existing firms in an industry over entrants by raising entry costs.

The industry growth cycle and the state of the farm economy may also influence pesticide innovation and composition of the pesticide industry. The industry growth cycle may affect innovation because, in the early stages of industry development, there are few existing products and thus little existing competition for new products. As an industry matures, new products face competition and must therefore be superior to be successful. This rise in product competition causes the number of new product introductions to decline and some firms to exit the industry (Klepper and Graddy, 1990).[3]

An expanding farm economy increases farmer demand for pesticides and thus influences expected firm profits. These expected profits give firms an incentive to innovate. In addition, farm sector demand may affect the composition and number of pesticide firms. Liebermann (1990), for example, contends that small firms are the most likely companies to exit as industry demand declines. Hence, improved farm sector demand should increase the number of innovative companies and may help small firms more than large ones.

Research Expenditures

The most basic input for developing a new pesticide is technical knowledge, which is obtained from experimentation and an understanding of biological and chemical sciences. However, this knowledge does not come free; it requires a substantial investment in research and development.

Baily (1972) argues that firms deplete research opportunities over time because the stock of possible innovations at any given level of basic science is limited. Advancements beyond the existing level of knowledge require expenditures on basic research. Hence, as research opportunities diminish at one level of science, firms must both invest in basic research to raise the existing level of science and make investments in applied research to generate new products.

High-cost research, like that required for chemical pesticides, may favor large firms. Large companies can better spread risks because they have diversified sources of revenue (Greene, Hartley, and West, 1977). Large companies may also be better able to take advantage of their research, because they have more market outlets for their products (Greene, Hartley, and West, 1977; Teece, 1982). Aucs and Audretsch (1987) show empirically that large companies are better able to innovate in capital-intensive differentiated goods industries. They also find that small companies have a competitive advantage in industries requiring a high level of skilled labor. In the pesticide industry, this suggests that large firms may be better able to develop very costly (chemical) pesticides, but that small firms may be able to compete effectively against larger rivals in the development of lower cost (biological) pesticides.

[3]As indicated later in "Farm Sector Changes," the pesticide industry reached maturity in the early 1980's when consumption stabilized. From 1982 to 1992, pesticide consumption rose by only 4 percent to 478 million pounds of active ingredient.

The Economic Environment of the Pesticide Industry

The economic environment in which pesticide companies operate determines their willingness to develop new pesticides. The main components of this economic environment are regulatory and demand conditions and the costliness of developing new pesticides. Regulatory costs affect innovation by raising the costs of bringing a pesticide to market. Market demand determines the potential revenues from new pesticides. Finally, the complexity of pesticide development influences development costs.

The Regulatory Environment

Congress enacted the Federal Food, Drug, and Cosmetic Act (FFDCA) in 1938 and the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) in 1948. These two legislative acts form the basis of modern pesticide regulation. Congress gave the FDA the authority to establish procedures for setting tolerances under the FFDCA. FIFRA requires that all agricultural chemicals for sale in interstate commerce be registered against manufacturers' claims of effectiveness and that the label state whether the pesticide is toxic to humans and fish and wildlife. Congress assigned authority to enforce FIFRA to the U.S. Department of Agriculture (USDA).

Prior to 1972, Congress amended FFDCA in 1954 and 1958 and FIFRA in 1959, 1964, and 1967. The FFDCA amendments required pesticide producers to thoroughly evaluate the safety of substances in food and supply data that show the acute, intermediate, subchronic (short-term), chronic (long-term), and other miscellaneous effects of the pesticides. They also stated that no food additive that increases cancer risk in humans or animals can be considered safe. The FIFRA amendments granted the USDA the authority to regulate all pesticides, closed a loophole that enabled companies to register pesticides when regulators felt more data were required, and made it necessary for pesticides to meet tolerances to gain registration (Hatch, 1982).

Hatch (1982) asserts that the carcinogenic and environmental effects of pesticides led to the 1972 amendment to FIFRA. During this time, Congress transferred jurisdiction over pesticide regulation from the USDA to the EPA. Under the 1972 FIFRA amendment, Congress greatly toughened existing pesticide laws by mandating that firms must reregister existing pesticides with the EPA, required the EPA to examine the effects of pesticides on fish and wildlife safety, and stipulated more rigorous chronic and acute toxicity testing. Overall, the amendment greatly increased the stringency of the health and safety data necessary to support pesticide registrations, required existing pesticides to be brought up to current standards, and gave the EPA authority to cancel or suspend pesticides that may pose unreasonable adverse health or environmental effects (Hatch, 1982).

Ambiguities existed in the 1972 amendment that were not resolved until the 1978 amendment. Some of the concern was over the costs of registering pesticides with low measurable environmental risks, the development of pesticides for minor crop markets (minor-use pesticides), and the reregistration of existing pesticides.[4] A major debate centered on the use of existing test data to register new pesticides. This situation arises when a second manufacturer wants to market a product similar to one already on the market. Overall testing costs and the costs to the new manufacturer of product development would be lower if the new manufacturer could use existing data. However, the original pesticide developer wants to prevent the new manufacturer from using the data because such use facilitates the market entry of a competitor. Hence, a conflict of incentives existed that could be settled only with new legislation.

The 1978 amendment eased data requirements for pesticides that posed low environmental risks and gave the EPA the right to reduce data requirements for minor-use pesticides. The 1978 legislation also strengthened State enforcement of pesticide use and allowed the registration of pesticides for specific local needs. Additionally, the amendment allowed certain crop uses that were not inconsistent with the label (Hatch, 1982). Finally, the 1978 amendment gave new manufacturers the right to use original producer data but required them to compensate the original developers. The amount of compensation was to be decided through arbitration. This aspect of legislation allowed registrations to move ahead on some products.

The 1978 amendment also changed the length of time that the EPA had to reregister all existing pesticides. EPA and the pesticide industry made very slow progress in reregistering new pesticides, however. In response, Congress enacted the 1988 FIFRA amendment, which required pesticide producers to demonstrate that all pesticides registered before 1984 meet current standards within 9 years. Payment for this reregistration program came from a 1-year payment and a yearly fee.

As noted above, the 1972 FIFRA amendment gave the EPA authority to impose stricter health and environmental standards on pesticides. Although the amendment mandated stricter health and environmental standards, it did not specify precise regulatory standards and guidelines necessary (rules) to prove the safety of a pesticide. As required by law, the EPA proposed preliminary rules and, after obtaining comments from the pesticide industry and other interested parties about these rules, issued final rules regarding pesticide use. These rules state the types of toxicological and environmental tests that must be performed to gain an EPA registration. They also indicate acceptable and unacceptable test outcomes.

EPA published the rules implementing the 1972 legislation in 1978 and 1982. Additional rules will likely be published in 1995, but EPA required the industry to perform new tests prior to the formal publication of the rules. For example, the pesticide industry adhered to some of the testing requirements stated in the 1978 rules in 1972 and abided by all of the 1978 testing requirements in 1977. The greatest increase in testing requirements occurred with the 1982 rules. The proposed 1995 rules have had a modest impact on testing requirements and are currently being adhered to by the pesticide industry.

As of 1992, the EPA required chemical pesticides to undergo 70 different types of tests.[5] These tests include a two-generation reproduction and teratogenicity study, a mutagenicity study, and toxicology studies [acute (immediate effect), subchronic (up to 90 days) and chronic (long-term effect) tests and as well as oncogenicity and chronic feeding study]. Some of these

[4]Minor crops are crops that have a low volume of agricultural output and include most fruits and vegetables. In 1989 there were 87 fruits and vegetables, such as avocadoes and peppers, with less than 100,000 planted acres and 22 fruits and vegetables, such as pears and lettuce, with more than 100,000 planted acres.

[5]As described in more detail in "Biological Pesticides," a tier approval system exists for biological pesticides. Under this system, biological pesticides have substantially fewer regulatory testing requirements. Additionally, fewer tests are required for all types of pesticides for nonfood applications.

tests can cost millions of dollars and can take several years to complete. Other tests are used to evaluate the effects of pesticides on aquatic systems and wildlife, farmworker health, and the environment.

Farm Sector Changes

The pesticide industry matured over the past two decades. Sales of herbicides, the most commonly used type of pesticide, rose from 101 million pounds to 374 million pounds of active ingredient between 1966 and 1976. Active ingredient sales increased to 456 million pounds by 1982 and remained almost unchanged thereafter, reaching 478 million pounds in 1992 (Osteen and Szmedra, 1989; Delvo, 1993). In terms of acres treated, farmers applied pesticides to almost 95 percent of their corn, cotton, and soybean acreage by 1982, and rates of use per acre were unchanged during the 1980's. Hence, new pesticides had to displace existing products to generate revenue after 1982.

After rising during the 1970s, farm sector demand for inputs stabilized during the 1980's. This change was partly due to a more competitive export environment and changes in farm programs that gave farmers an incentive to reduce planted acreage. Total grain production in the United States rose from 187 million metric tons to 332 million metric tons from 1970 to 1982, but had dropped to 283.7 million metric tons by 1989. Reflecting these changed circumstances, farm real estate values dropped from $304 billion in 1982 to $215 billion in 1989 (USDA, 1974 and 1991).

The Chemical Pesticide Development Process

The process of developing new pesticides is lengthy and costly. Researchers use either a random or directed approach to screen numerous chemical candidates for their potential as pesticides. Under the random approach, technical personnel experiment with chemical compounds that they think may be useful as chemical pesticides. With the directed approach, scientists examine chemical compounds known for their effectiveness in controlling pests. Hatch (1982) suggests that the random approach has a greater potential for discovering revolutionary new products but a lower probability of success than the directed approach.

The development process follows discovery and comprises a number of steps. First, technicians conduct secondary screenings in which biological thresholds are determined. Next, a multi-disciplinary group determines which compounds deserve further investigation. Afterwards, technicians synthesize promising chemicals in larger quantities. They use these larger batches of chemicals to conduct effectiveness tests in the laboratory and the field, determine whether the chemical is toxic to humans and fish and wildlife, and estimate production costs. These technical and cost data are passed on to managers who determine whether the company should pursue small-scale field testing.

Chemicals that managers select for further consideration must pass through a series of more demanding field tests. First, technical personnel use small-scale field testing to determine the effectiveness of the chemical compound relative to existing pesticides. They also evaluate the impact of soil, sunlight, microbes, and climate on its effectiveness. If the pesticide candidate fares well against existing pesticides, the firm obtains an experimental use permit (EUP) from the EPA. An EUP allows the company to conduct larger field tests. EPA grants an EUP only if it believes the evidence reveals no adverse environmental effects will occur. If the EPA does not grant a permit, then the company must either specify a new field test that meets EPA specifications or abandon pesticide development.

In larger field tests, technicians conduct metabolic, environmental, residue, and toxicology studies to determine the impact of the compound on humans, mammals, fish, and wildlife. Simultaneously, chemical and production personnel develop formulation techniques and production methods. If metabolic, environmental, residue, and toxicology studies indicate that the pesticide may pass EPA scrutiny and other studies suggest the pesticide will be effective, then a firm applies for pesticide registration.[6] In obtaining this registration, a firm first registers a pesticide for use on a particular crop, such as corn. This registration allows farmers to use the pesticide only on corn. If the firm wants to sell the pesticide for use on another crop, such as tomatoes, then it must register the pesticide for use on that crop (tomatoes).

The EPA must approve all pesticides for each crop on which they are used. It makes its judgment based on data supplied by the company and, after examining the data, either approves the pesticide, asks for more data, or rejects the application. Accordingly, the process of submitting data is repeated for each crop and may involve additional costs because pesticide registration requirements often mandate different test data for different crops. A pesticide can be rejected for use on all crops or rejected only for some crops. For example, a pesticide may be rejected for use on food crops but not ornamentals.

[6]In this report, "pesticide registration" refers to receipt of legal authority from the EPA for the first-time use of a new pesticide.

Giannesi and Puffer (1992) note that many herbicides for major crops are phytotoxic to fruits and vegetables if not applied under the right conditions. Accordingly, early in the pesticide development process, a firm must decide whether to develop a pesticide for either major or minor crops. This report examines i) whether a rise in regulatory-related testing costs influences the decision to develop pesticides mainly for major crop markets and ii) whether it affects the number of total uses.

It is extremely important for firms to know which tests to conduct and the type of data required by the EPA. A firm can perform some unnecessary tests and drive up its product development costs. Alternatively, if a company does not conduct enough tests or has poor data, then the need for additional tests or revised data delays the commercialization of the product and results in lost revenue.

The capacity to determine whether a chemical compound can be both effective and pass EPA regulatory requirements is essential for low-cost development of new pesticides. Although most chemicals that are not registered are rejected at the screening stage, many go through various stages of the development process, and some are submitted to the EPA for registration. The longer a chemical is developed, the higher are the development costs. Hence, the ability to accurately select and then develop only chemicals that are both effective and meet EPA guidelines is essential for pesticide development.

Research expenditures and the new pesticide development cycle rose substantially over the 1972-91 period. Deflated average industry research costs in 1982 dollars rose from $91.3 million per year over the 1972-76 period to $340.8 million over the 1987-91 period.[7] USDA estimates indicate that new pesticide development costs rose from $16 million per new pesticide in 1972 to $42.5 million in 1987 in 1982 dollars (table 1). Meanwhile, the pesticide development cycle (the time required to bring a pesticide from initial screening to market) rose from 5 years in 1967 to 10 years in 1987. Estimates of new pesticide development costs, which include regulatory-related testing costs for the initial registration, are based on the definition for $RESEARCH_{i,t}$ in appendix table A1. This development cost includes the costs of pesticides that do not reach the market due to either regulatory or technical failures.

[7]Some of the increase in research costs can be attributed to greater difficulty in finding chemicals that can be used as pesticides. NACA surveys indicate that the number of chemicals screened per new registered pesticide rose from 8,500 during the 1970-73 period to about 21,600 chemicals during 1986 and 1987.

Both the increase in pesticide development costs and the new pesticide development cycle can deter firms from developing certain types of chemical pesticides. The increase in pesticide development time is costly because companies gain patent protection during the development process. Thus, a longer development time gives a pesticide company less time to sell a pesticide as a proprietary product. Higher development and environmental testing costs discourage innovation because a product must then realize greater revenue in order to be profitable.

Higher testing costs were a major contributor to the increase in development costs and may have increased new pesticide development cycles.[8] New pesticide testing costs as a percentage of research expenditures rose from 9.7 to 25 percents and test costs for all (new and existing) pesticides rose from 18 percent of total research expenditures in 1972 to 47 percent in 1989 (table 1).[9]

The greater increase of all testing costs than for new pesticide testing costs reflects higher reregistration costs. The 1988 amendment to FIFRA greatly strengthened the pesticide reregistration requirement. Pesticide reregistration requires firms to generate new toxicological and environmental data for each currently approved pesticide.

Firms would undertake some toxicological and environmental testing in the absence of regulation because farmers want pesticides that are safe to use and do not adversely affect the environment (Beach and Carlson, 1993). Nonetheless, EPA cost analyses for the 1978, 1982, and the currently proposed rules indicate that the cost of regulatory-required tests doubled between 1972 and 1993 and strongly correlates with the increase in industry-reported toxicological and environmental testing costs (testing costs). In addition, the number of employees at the pesticide division of the EPA increased from 432 to 827 over the 1972-89 period (table 1). (EPA adds workers in order to reduce the time required to review the data necessary to register pesticides. Thus, an increase in employment reflects a greater number and complexity of tests.)

[8]As indicated earlier, the EPA established new rules in 1978, 1982, and 1995. The 1978 rules dealt mainly with testing the chronic health effects of pesticides and, in terms of the costs published by the EPA in the *Federal Register*, increased required testing costs by 30 percent over that which existed in 1972. The 1982 rules included many new environmental and chronic tests and increased testing costs by 95 percent over that which existed in 1972. The current rule changes have increased costs by about 100 percent over that which existed in 1972.

[9]Testing costs for approved pesticides are for reregistration or for registering pesticides for additional crops.

Table 1—New chemical pesticides, industry research, and regulatory effort for 1972-91

Year	New chemical pesticide registrations		Industry research	New pesticide regulatory costs	All pesticide regulatory costs[3]	Product development[4]	Workers at EPA pesticide division
	Major firms	All firms[1]					
	----------------Number----------------		Million $1982	-----------------Percent-----------------		Years	Number
1972	12	16	98.5	9.7	18.0	7	432
1973	4	13	87.9	11.4	19.0	7	461
1974	11	22	65.7	17.2	18.0	8	591
1975	12	25	85.7	17.7	20.0	8	631
1976	7	8	107.7	21.2	33.0	8	671
1977	1	2	114.2	20.0	31.0	8	639
1978	0	5	127.3	18.1	29.0	8	657
1979	9	17	127.7	18.5	35.0	8	670
1980	9	11	129.2	18.7	29.0	8	755
1981	5	14	174.3	17.3	27.0	8	677
1982	7	18	204.4	18.9	30.0	9	568
1983	8	15	216.4	19.8	31.0	9	525
1984	7	11	245.5	18.7	28.0	9	555
1985	4	10	370.4	20.8	34.0	10	591
1986	8	9	290.3	25.9	39.0	10	580
1987	4	6	284.9	24.2	40.0	10	575
1988	4	9	305.9	24.5	41.0	10	602
1989	10	15	330.4	25.1	47.0	10	621
1990	3	6	392.8	25.0	55.0	11	734
1991	3	7	390.1	25.0	60.0	11	827
1972-76	46	84	91.3	13.0	22.0	7.6	497
1977-81	24	49	134.5	12.6	30.0	8.0	680
1982-86	36	63	265.4	14.2	32.0	9.6	564
1987-91	24	43	340.8	24.8	49.0	10.4	672

[1]These include only chemical pesticides. Major companies are firms ranked among the top 20 companies at least once over the 1972-91 period. [2]Includes all new pesticide industry research spending for health and environmental purposes, such as toxicology studies, as a percentage of all new pesticide industry research. [3]Includes all industry research spending for health and environmental purposes, such as toxicology studies, as a percentage of all industry research. [4]Years required to develop a new pesticide.

Effects of Regulatory-Related Testing Costs

Four hypotheses were empirically examined regarding regulatory-related testing costs. Two hypotheses are based on the relationship between testing costs and potential revenues. To gain registration, which is required of each pesticide for each crop on which it is used, a firm must conduct toxicological and environmental tests and supply the data to the EPA.[10]

[10]The regulatory costs associated with registering a pesticide for a second use, such as tomatoes for a pesticide currently registered for corn, depends on the type of data required for approval. If data requirements are similar to a currently registered use, then the costs of registering the pesticide for use on tomatoes is low. If data requirements are dissimilar, then the costs of registering a pesticide for use on tomatoes is high.

Conducting tests for registration, which permits use of a pesticide on a new crop, can be very costly. At the same time, potential revenues can vary from less than a million dollars for some minor crops, such as many fruits and vegetables, to over a billion dollars for corn. This testing cost-revenue relationship suggests that as testing costs rise, it becomes unprofitable for firms to develop pesticides for some minor crops. Hence, a rise in regulatory-related testing costs should cause the number of new pesticide registrations to decline and the ratio of major-use pesticides to all pesticides to rise. In addition, if firms focus their development effort on pesticides for major crops, then pesticide sales per new pesticide (pesticide market size) should rise.

Regulatory-related testing costs also have an impact on pesticide toxicity.[11] Greene, Hartley, and West (1977) and Lichtenberg, Spear, and Zilberman (1993) believe that greater testing costs cause firms to develop pesticides that will be used on at least one major crop and many minor crops. They suggest that these wide-spectrum pesticides may be highly toxic to humans and fish and wildlife because they must be effective against numerous pests.[12] However, the purpose of additional testing is to reduce the number of toxic pesticides that reach the market. As a result, it may be that an increase in the number of tests reduces the number of pesticide candidates that can pass regulatory scrutiny because pesticides that formerly complied with regulatory standards may no longer meet new guidelines. Hence, an increase in regulatory stringency may cause a reduction in pesticide toxicity to humans and fish and wildlife.

A fourth hypothesis emerges from the relationship between regulatory-related testing costs and minimum firm size. A rise in testing costs makes it necessary for firms to generate greater revenues to remain profitable. Firms that can generate substantial sales from each new pesticide for major crop markets or have more diverse sources of income are favored over more specialized firms focusing their research on minor crop markets. As a result, higher testing costs favor large chemical pesticide firms over small chemical pesticide firms. In addition, higher testing costs favor multinational chemical pesticide firms over strictly domestic chemical pesticide companies because multinational firms have more diverse sources of income and a product failure in one country may be a useful pesticide in a different market.[13] See the section entitled "Causes of Changes in New Pesticide Innovation and Industry Composition" for justification.

[11]Unless otherwise noted, we define a toxic pesticide as a pesticide that has a Class 1 acute toxicity rating, which means the chemical pesticide is highly toxic to humans for a brief period after application before it degrades, or has possible chronic effects, or is toxic to fish and wildlife, or has other side-effects noted on the label. Although these remarks are included on the label, the EPA has rigorous approval requirements and tolerances that prevent harmful exposures to either humans or fish and wildlife.

[12]Chemical pesticides must be biologically active to be effective. As a consequence, many are toxic not only to pests but also to humans and fish and wildlife. As toxicity to pests rises, so may toxicity to humans and fish and wildlife.

[13]Here we are discussing only chemical pesticide firms. There are several small biological pesticide firms that successfully compete against their larger rivals because biological pesticides have much lower development and regulatory costs.

New Pesticide Registrations

We empirically examine the impact of greater regulatory-related testing costs on new pesticide registrations. Historical evidence supports our hypothesis that testing costs negatively affect new pesticide registrations. The number of chemical pesticides registered for use on its first crop (pesticide registrations) by major pesticide companies dropped from 46 to 24, and pesticide registrations by all companies dropped from 84 to 43 between the 1972-76 and 1987-91 periods (table 1). Major pesticide innovators are companies listed in the top 20 firms in terms of pesticide sales for at least 1 year during 1972-91.

Regression results indicate that control variables—research expenditures, pesticide industry growth, and market share growth—and regulatory-related testing costs affect the number of new pesticide registrations (Ollinger and Fernandez-Cornejo, 1994b). A 10-percent ($11.2 million in 1972 dollars) increase in new pesticide testing costs causes a 2.7-percent reduction in new pesticide registrations.

As noted earlier, we define new pesticide testing costs as development- and regulatory-related testing costs of the first registered use of a pesticide. These costs understate regulatory-related testing costs because they do not include future use registration and reregistration expenses. Accordingly, we also consider regulatory-related testing costs for all registration and reregistration expenses (all testing costs).[14] We found that a 10-percent ($67 million) increase of all testing costs caused a 4.5-percent reduction in new pesticide registrations. The complete effect of either initial pesticide registration or total testing costs would not be completely felt for about 11 years because higher costs affect pesticides throughout the pesticide development cycle (currently 11 years in duration).[15]

New Pesticide Market Size

As hypothesized, a rise in regulatory-related testing costs should cause firms to focus their research effort on the development of pesticides for major crop markets

[14]As noted earlier, firms must provide test data to the EPA in order to register pesticides for use on crops other than those permitted by the initial registration. In addition, Congress mandated that firms register all existing pesticides to comply with current standards.

[15]We assume that point elasticities are applicable in determining the hypothetical impact of an increase in regulatory costs on new pesticide registrations. The regression model is presented in appendix equation A1. The variables are defined in an accompanying table of variables and Appendix B. For further discussion, see Ollinger and Fernandez-Cornejo (1994b).

and cause the market size for new pesticides to rise. The size of the market for new pesticides rose from an average of $6.69 million in 1972 dollars over the 1973-77 period to $17.28 million over the 1986-89 period (table 2).[16] Regression results indicate that regulatory-related testing costs for initial pesticide registration, research and development expenditures, changes in the farm economy, and growth in pesticide company market share affect the size of the market for new pesticides (Ollinger, Aspelin, and Shields, 1994).

Higher testing costs make it necessary for a firm to generate more revenue from each new pesticide that it introduces. Accordingly, a firm must abandon pesticide development for crop markets that are too small to generate the revenues needed to meet testing expenses. Thus, firms develop fewer pesticides and those pesticides that do come to market are designed for major rather than minor crop markets. Consistent with this hypothesis, regression analyses show that a 10-percent increase in testing costs for initial registration increases the pesticide market size required to meet the added costs by about 13.9 percent. Results also suggest that a 10-percent increase in total pesticide testing costs increases the pesticide market size by 10 percent. Similar to new pesticide registrations, it would take 11 years for the complete impact of changes in testing costs to be felt.[17]

Chemical pesticides must be registered for each crop with the EPA before use. The number of uses for which a pesticide is registered may give an idea of how much revenue the pesticide can generate. For example, a pesticide that is registered for 50 crops can realize greater potential revenue than a pesticide registered for 20 crops if all crop markets are of equal size. Crop market sizes differ, however. A pesticide registered for larger crop markets, such as corn, has a greater potential revenue than a pesticide for a smaller crop

[16]Sales of new pesticides depend on farmer education of their quality, which causes a lag between the introductory year and the year when the pesticide reaches its market potential. Hence, we defined new pesticide product market size as the sum of sales generated by one product during the current year and 2 subsequent years. All values are deflated to 1972 dollars with the GNP deflator. We used a 3-year period because, by this time, pesticide rankings had stabilized. For example, if pesticide "A" has sales of $5 million in 1972, $10 million in 1973, and $15 million in 1974, then its new pesticide market size is $30 million. Average new pesticide market size for pesticide "A," "B" ($2 million in sales over 3 years), "C" ($6 million in sales over 3 years), and "D" ($10 million in sales over 3 years) equals $12 million in 1972 dollars.

[17]Appendix equation A2 is the regression model used in the analysis of new pesticide product market size.

Table 2—New pesticide product market size and share of pesticide sales for 1972-89

Year	New pesticide product market size	New pesticide share of total pesticide sales[1]
	Million $1972 [2]	*Percent*
1972	n.a.	n.a.
1973	3.54	n.a.
1974	7.58	3.20
1975	7.65	2.60
1976	6.71	6.80
1977	7.97	10.70
1978	7.08	5.83
1979	3.20	3.74
1980	1.52	2.72
1981	4.76	0.66
1982	4.71	0.89
1983	2.45	2.29
1984	4.60	4.04
1985	7.76	1.24
1986	16.50	2.05
1987	25.90	5.70
1988	18.60	7.10
1989	8.15	6.00
1973-77[3]	6.69	5.82
1978-81	4.14	3.24
1982-85	4.88	2.11
1986-89	17.28	5.21

n.a. = Not available.

[1]Current year sum of sales of all pesticides that were introduced within the last 3 years divided by current year industry sales.

[2]Sum of 3 years of sales for each new pesticide. More than 1 year of sales is necessary because it takes time for farmers to become aware of the qualities of the new pesticide. We assume that a 3-year learning period occurs because sales rankings between 3- and 4-year sales periods did not change for over 95 percent of the new pesticide registrations. Mathematically, we express the relationship as follows:

$$PSALES_{i,j,t} = \sum_{z=0}^{z=2} PSALES_{i,j,t+z}$$

where $PSALES_{i,j,t+z}$ is the discounted sales of firm *i*'s *j*th product in year *t+z*.

[3]Covers the 1973-77 period for "New pesticide market size" and the 1974-77 period for "New pesticide share of total pesticide sales."

market, such as avocados.[18] Hence, there are three possible outcomes for crop market uses as new pesticide market size rises: crop market uses could rise without a proportional change for major crop markets; crop market uses could rise and firms may develop proportionally more pesticides for major crop markets; or firms could become discouraged from developing pesticides for minor crop markets and may focus on major crop markets.

Pesticides can be registered for use on individual crops in any of eight crop categories: major field crops, minor field crops, major vegetables, minor vegetables, major fruits and nuts, minor fruits and nuts, nursery, and other crops. Major field crops include corn, cotton, sorghum, soybeans, and wheat. Minor field crops are alfalfa, barley, clover, flax, hops, lentils, mint, oats, peanuts, peas, potatoes, rice, rye, safflower, sunflower, sugarbeets, sugarcane, sweet potatoes, and tobacco. Major vegetables include asparagus, beans, broccoli, cabbage, carrots, cauliflower, cucumbers, lettuce, onions, sweet corn, and tomatoes. Minor vegetables include 35 other vegetables having less than 100,000 acres planted. Major fruits and nuts include apples, grapes, citrus, nectarines, peaches, pears, plums/prunes, strawberries, almonds, filberts, pecans, and walnuts. Minor fruits and nuts include 51 other fruits and nuts with generally less than 100,000 acres planted. Nursery crops include conifers, grass and turf, greenhouse, and five other nursery uses. Other crops consist of forage and pasture, forestry, storage, and five other non-crop and non-nursery uses.

As testing costs rose, registrations for new pesticides for major field crops and nursery and other crops dropped by about 50 percent between 1972-76 and 1985-89 (table 3). More dramatic was the 72-percent decline in crop registrations for minor field crops, 92-percent drop in registrations for vegetables, and 75-percent reduction in crop registrations for fruits and nuts. Hence, the reductions in crop market registrations for minor field crops, vegetables, and fruits and nuts are much greater than for major field crops and nursery and other crops.

Crop market and pesticide type, such as herbicide, insecticide, or fungicide, also suggests an impact of testing costs on crop market use. Herbicides have about 62.5 percent of the U.S. market for pesticides. Thus, a firm may be more likely to cover research and testing costs by developing a herbicide for major field crops than any other type of pesticide for any other crop market. Herbicides showed almost no decline for use on either major field crops or for crops not for human consumption, such as nursery crops (table 3).[19] In contrast, herbicide uses for minor field crops dropped by about 59 percent; herbicide uses for vegetables declined by over 90 percent; and herbicide uses for fruits and nuts dropped by about 50 percent. Even more dramatic was the contrast between herbicide uses for major field crop markets and insecticides for all markets, which dropped by 74 percent.

Econometric analyses indicate that a 15-percent ($16.8 million in 1972 dollars) increase in new pesticide testing costs causes firms to abandon the development of pesticides for one of the eight crop categories. Regression analyses also suggest that higher testing costs caused companies to target major crop markets and thus reduce pesticide registrations for minor crop markets. A 10-percent increase in testing costs causes a 2-percent increase in the proportion of pesticides for major crop markets compared with pesticides for all crop markets. The changes would not be fully felt for about 11 years.

Product liability costs are a potential cost of registering a pesticide for a particular crop use. These costs arise when farmers sue a pesticide manufacturer for damages caused by a pesticide. The damage can either be on the crop on which the pesticide was used or a different crop. Damage can arise in many ways. One example is the wind blowing a pesticide on crops for which the pesticide is not suitable. Giannesi and Puffer (1992) report that most liability claims are for less than $1 million but that DuPont paid $120 million in claims to nursery growers for damages associated with benomyl, a fungicide. No data are available on total liability costs but clearly liability costs can discourage pesticide firms from registering pesticides for some crop uses, particularly minor crops because the potential revenues are much smaller.[20]

New Pesticide Safety

Chemical pesticides must be biologically active in order to control pests. However, many are toxic to humans and fish and wildlife. As a result, producers must indicate the acute toxicity rating (I, II, III, or IV) on the label for each pesticide container. A rating of I is the most toxic. This rating is based on LD 50 values,

[18]Giannesi and Puffer (1992) report that fruits and vegetables account for only 15 percent of pesticide consumption, while corn and soybeans account for over 50 percent of pesticide consumption.

[19]Crops that are not for human consumption have fewer test requirements than pesticides for human consumption.

[20]Liability concerns are not included in our analyses because all of the major decisions against companies have occurred too recently to affect innovation over the 1972-91 period. Additionally, liability laws have not changed over the past 30 years.

Table 3—New pesticide registrations, by crop market and type of pesticide, 1972-89

Year[1]	Crop market registrations: Major field[2]	Minor field[3]	Veg.[4]	Fruit/ nut[5]	Nursery/ other[6]	Crop market and type of pesticide: Major field h,i,o[7]	Minor field h,i,o	Veg. h,i,o	Fruit/ nut h,i,o	Nursery/ other h,i,o
						Number				
1972 (12)	8	19	20	69	14	2,3,0	4,3,1	3,5,0	4,4,2	3,2,1
1973 (4)	5	9	23	42	4	1,1,1	2,1,2	4,0,2	3,1,2	0,2,0
1974 (11)	12	25	48	74	9	3,2,1	4,2,1	3,4,2	3,2,2	2,2,2
1975 (12)	12	15	4	16	10	4,1,0	5,1,1	2,1,0	4,3,0	7,1,1
1976 (7)	8	9	5	22	5	2,0,0	2,0,0	3,0,0	3,0,0	2,0,2
1977 (1)	0	0	0	0	5	0,0,0	0,0,0	0,0,0	0,0,0	2,0,1
1978 (0)	0	0	0	0	0	0,0,0	0,0,0	0,0,0	0,0,0	0,0,0
1979 (9)	13	20	99	101	22	1,4,2	1,3,3	2,6,6	2,5,6	3,5,2
1980 (9)	4	6	1	0	9	3,1,0	2,0,0	0,1,0	0,0,0	1,3,0
1981 (5)	2	4	3	13	4	0,0,2	0,0,1	0,0,2	0,0,4	0,0,3
1982 (7)	6	2	1	2	8	2,2,1	1,0,0	0,1,0	0,1,0	1,0,2
1983 (8)	5	11	24	73	12	3,0,0	4,0,0	5,0,2	4,0,2	3,2,1
1984 (7)	3	0	2	19	9	0,2,0	0,0,0	0,2,0	0,3,2	2,2,3
1985 (4)	0	0	2	0	4	0,0,0	0,0,0	0,2,0	0,0,0	2,2,0
1986 (8)	8	8	2	0	7	6,0,0	3,0,0	1,0,0	0,0,0	3,1,0
1987 (4)	4	4	0	0	7	3,0,0	2,0,0	0,0,0	0,0,0	2,1,0
1988 (4)	4	3	2	0	1	3,1,0	2,1,0	0,2,0	0,0,0	1,0,0
1989 (10)	6	7	2	50	4	2,1,1	2,0,2	0,0,2	2,2,4	2,0,1
1972-76 (46)	45	77	100	203	42	12,7,2	17,7,5	15,10,4	17,10,6	14,7,6
1977-81 (24)	19	30	103	114	40	4,5,4	3,3,4	6,7,8	2,5,10	6,8,6
1980-84 (36)	20	23	31	107	42	8,5,3	7,0,1	5,4,4	4,4,8	8,7,9
1985-89 (30)	22	22	8	50	23	14,2,1	9,1,2	1,4,2	2,2,4	10,4,0

[1]Numbers in parentheses are total new pesticides; table does not include 1990 with 3 and 1991 with 3 new pesticide registrations. Over 1982-86 period there were 34 and over 1987-91 there were 24 new registrations. The number of pesticide crop market registrations and types exceeds the total number of new pesticides because one pesticide can have many crop uses.

[2]Major field: corn, cotton, sorghum, soybean, and wheat.

[3]Minor field: alfalfa, barley, clover, flax, hops, lentils, mint, oats, peanuts, peas, potatoes, rice, rye, safflower, sunflower, sugarbeets, sugarcane, sweet potatoes, tobacco.

[4]Veg. is major and minor vegetable categories combined. These categories include asparagus, beans, broccoli, cabbage, carrots, cauliflower, cucumber, lettuce, onions, sweet corn, tomatoes, and 35 other vegetables, having less than 100,000 acres planted.

[5]Fruit/nut is major and minor fruit and nut categories combined. These categories include apples, citrus, grapes, nectarines, peaches, pears, plums/prunes, strawberry, almonds, filberts, pecans, walnuts, and 51 other fruits and nuts, products with generally less than 100,000 acres planted.

[6]Nurse/other is nursery and other combined. This category includes conifers, greenhouse, grass and turf, five other nursery uses, forage and pasture, storage, forestry, and five other non-crop and non-nursery uses.

[7]h is herbicides, i is insecticides, and o is other pesticides, such as fungicides, miticides, and others.

which are the dose of a toxicant necessary to kill 50 percent of the test animals studied within the first 30 days following exposure.

Pesticides may also have chronic health effects, may be harmful to either fish or wildlife, or may have other environmental or health consequences. The EPA requires manufacturers to note on the label side effects, such as chronic human effects and harm from inhalation, skin absorption, or eye damage.[21] Additionally, the harmful effects of pesticides on fish and wildlife must be noted on the registration.

[21]The EPA established residue tolerances to prevent risks from chronic dietary exposure of humans to pesticide residues. Hence, crops sprayed with a pesticide with potential side effects are safe for human consumption.

The number of chemical pesticides with any chronic health effects dropped by 83 percent and the number of new pesticides harmful to fish and wildlife dropped by 33 percent between the 1972-76 and 1985-89 periods (table 4). However, the number of pesticides with a Class I acute toxicity rating changed very little. Acute toxicity changed very little because the 1972 FIFRA amendment was targeted to reduce the long-term (chronic) and environmental effects of pesticides.

Many chemical pesticides accounted for in table 4 are not highly toxic to humans and fish and wildlife. This difference in health and environmental consequences allows pesticides to be classified as "more" or "less" toxic. "More toxic" pesticides are those that have a Class I acute toxicity rating or chronic, fish and wildlife, or other effects. "Less toxic" pesticides are all others.

Regression analyses indicate that higher testing costs encourage the development of less toxic pesticides. A 10-percent ($11.2 million in 1972 dollars) increase in testing costs is associated with a 2.8-percent increase in the proportion of "less toxic" pesticides.[22]

Between the 1975-78 and 1986-89 periods, sales of new pesticides with either chronic or fish and wildlife effects as a share of total pesticide sales fell by 84 percent, "more toxic" new pesticide sales as a share of total pesticide sales declined by 87 percent, and "less toxic" new pesticide sales as a share of total pesticide sales rose by 123 percent (table 4). Hence, there has been a significant shift to "less toxic" pesticides, both in terms of number of new registrations and sales of new chemical pesticides.

Industry Composition

Over the past 20 years, there were a number of changes in the pesticide industry. Two of the biggest changes were the decline in the number of innovative pesticide companies and the transition of the pesticide industry from one with a strong domestic component to an international industry. The number of pesticide companies fell from 33 to 19 from 1972 to 1989 (table 5). This decline did not increase industry concentration. The four-firm concentration ratio dropped from 0.496 to 0.483, and the eight-firm concentration ratio dropped from 0.795 to 0.775. Also of importance was the increase in the foreign-based company market share from 18 to 43 percent and the rise of foreign-based firms in the U.S. market from three to nine firms. Similarly, foreign sales by U.S. companies rose to about 50 percent of their total sales (table 5). As the decline in the number of companies in the pesticide industry may suggest, there were numerous mergers between chemical pesticide companies between 1972 and 1989. The most significant impact of these transactions was to expand the market share held by companies with a small U.S. presence.

Results of an econometric study indicate that testing costs, research expenditures, the stage of the industry growth cycle, and farm sector economic conditions played major roles in influencing both the number of companies in the industry and the market share held by foreign-based companies (Ollinger and Fernandez-Cornejo, 1994a). It is estimated that a $100-million increase in testing costs would result in an exit of seven companies over 4 years. Five of the seven departing companies would be relatively small. A $100-million increase in testing costs would also result in about a 13-percent increase in foreign-based company market share over 4 years.[23] An increase in market share by foreign-based companies suggests that changes in the industry favored companies with numerous markets for pesticides. Like the foreign-based firms, U.S. firms expanded into Europe and Asia as a way to gain access to more markets.

Econometric evidence also indicates that acquiring firms in mergers tended to be more profitable, have lower regulatory fines and penalties, and have a high level of world sales but a low level of U.S. sales. Regulatory fines and penalties include fines levied by the EPA for violations of environmental standards and sales lost because the EPA either restricted or banned the use of pesticides that the company was selling.[24]

Regulation and Nonchemical Pesticide Alternatives

There are two major nonchemical pesticides: biological organisms and genetically modified plants. Biological pesticides employ naturally occurring toxins to reduce the number of pests. The EPA favors the use of these naturally occurring organisms and plants to control

[22]Appendix equation A5 is the regression model for the variables affecting pesticide toxicity.

[23]Appendix equations A6 and A7 are the models of regulation and industry composition.

[24]Appendix equation A8 is a model of the determinants of merger choice. The sum of regulatory fines and penalties over a 10-year period amounted to 34 percent of sales for firms that were acquired by another company. One of these firms had fines and penalties equal to 83.2 percent of sales and two others had fines and penalties equal to about 75 percent of sales over 10-year periods. In contrast, firms that remained in the industry had average fines and penalties of 5.6 percent over a 10-year period. One firm had fines or penalties equaling 40 percent of sales.

Table 4—New pesticide toxicity, 1972-89

Year	Toxic pesticides					New pesticide sales as a share of total pesticide sales			
	Class 1 acute[1]	Chronic	Fish/ wildlife	Other	Total more toxic[1]	Chronic/ fish/ wildlife	Total more toxic	Total less toxic	More toxic new pesticide sales as a share of all new sales[2]
	Number					Percent			
1972	3	1	3	4	5	n.a.	n.a.	n.a.	n.a.
1973	1	2	5	2	7	n.a.	n.a.	n.a.	n.a.
1974	2	2	4	2	6	n.a.	n.a.	n.a.	n.a.
1975	1	1	3	1	6	0.96	1.06	1.53	41.0
1976	0	1	3	1	3	4.21	4.38	2.44	64.0
1977	1	1	1	0	1	7.03	7.28	3.38	68.0
1978	0	0	0	0	0	5.21	5.39	0.44	92.0
1979	2	1	5	2	7	3.52	3.52	0.22	94.0
1980	2	2	2	1	5	2.31	2.31	0.41	85.0
1981	1	0	2	1	3	0.44	0.44	0.22	67.0
1982	1	1	3	3	5	0.31	0.31	0.58	35.0
1983	1	2	4	0	6	0.61	0.61	1.68	27.0
1984	0	2	3	0	4	2.18	2.19	1.86	54.0
1985	1	1	3	2	4	0.52	0.52	0.72	42.0
1986	1	0	2	0	2	0.78	0.83	1.21	41.0
1987	3	0	3	3	6	0.53	0.62	5.04	11.0
1988	2	0	2	2	3	0.65	0.75	6.40	10.0
1989	1	0	2	1	3	0.86	1.17	4.81	20.0
1972-76[3]	7	6	18	8	27	4.35	4.53	1.95	66.0
1977-81[4]	6	4	10	4	16	1.65	1.65	0.36	70.0
1980-84[5]	5	7	13	5	23	0.91	1.04	1.21	39.0
1985-89[6]	7	1	12	8	18	0.71	0.58	4.37	21.0

n.a. = Not available

[1]Less than sum of all side effects because one pesticide may have multiple side effects.

[2]Numbers less than 0.50 mean that less than half of all new pesticide sales are less toxic pesticides.

[3]Covers the 1975-78 period for the percent sales categories.

[4]Covers the 1979-82 period for the percent sales categories.

[5]Covers the 1982-85 period for the percent sales categories.

[6]Covers the 1986-89 period for the percent sales categories.

pests because these organisms are viewed as posing fewer health and environmental risks than chemical pesticides.[25] Accordingly, many biological pesticides have no tolerances. As a result, farmers can spray them on plants up until harvest. The environmental benefits of reduced use of chemical pesticides are also significant. Crutchfield, Hansen, and Ribaudo (1993) suggest that the environmental side effects of chemical pesticides include the cost of providing alternative sources of drinking water, increased treatment costs for public and private water systems, lost boating and swimming opportunities, and damage to recreational and fishery resources.

Genetically modified plants are plants developed through the use of biotechnology. There are three types of plants that are relevant to pest control: herbicide-tolerant plants (which can tolerate certain types of herbicides), insect-resistant plants (which can withstand attacks by certain insects), and virus- and other pest-resistant plants (which are immune to some types of plant viruses and other plant pests). As of September 1994, several genetically modified plants had been commercialized and had elicited optimism that genetically modified

[25]Hutchins and Gehring (1993) indicate that *Bacillus thuringiensis*, a commonly used biological pesticide, would be highly toxic if injected into humans. They also suggest that many naturally occurring pesticides are highly toxic.

Table 5—Pesticide industry firms ranked by company size, concentration ratios, and the U.S. pesticide market share of foreign-based firms for 1972-89[1]

Year	All firms	Small firms	Large firms	4-firm concentration ratio	8-firm concentration ratio	Foreign firm U.S. market share[2]	Foreign firm entrants[3]	Share of U.S. firm output abroad[4]
	Number			*Percent*			*Number*	*Percent*
1972	33	16	17	0.496	0.795	18	0 (0)	n.a.
1973	34	17	17	0.501	0.786	16	1 (3)	n.a.
1974	34	17	17	0.484	0.764	20	1 (3)	23 (54)
1975	36	18	18	0.487	0.756	20	2 (6)	18 (53)
1976	36	18	18	0.478	0.758	21	2 (6)	25 (56)
1977	36	18	18	0.441	0.712	20	2 (6)	25 (56)
1978	36	18	18	0.421	0.684	22	2 (6)	17 (55)
1979	36	18	18	0.407	0.675	21	3 (8)	20 (54)
1980	34	16	18	0.394	0.657	21	3 (9)	25 (60)
1981	34	16	18	0.378	0.633	21	3 (9)	24 (60)
1982	33	15	18	0.372	0.626	21	3 (9)	29 (64)
1983	32	14	18	0.392	0.644	21	3 (9)	33 (64)
1984	29	10	19	0.402	0.646	23	3 (10)	25 (56)
1985	28	9	19	0.385	0.613	28	4 (14)	31 (64)
1986	26	8	18	0.380	0.616	29	4 (15)	32 (62)
1987	23	8	15	0.454	0.712	36	4 (17)	33 (64)
1988	23	8	15	0.466	0.743	38	4 (17)	30 (55)
1989	19	6	13	0.483	0.775	43	6 (32)	n.a.

n.a. = Not available.

[1]Companies introduced at least one new product over the 1972-89 period or were among the top 20 companies at one point over the 1972-89 period. The starting date is either the first year in which a company had sales levels among the top 20 companies or 4 years prior to their first new product as reported in Aspelin and Bishop (1991).

[2]Share of production includes the production of foreign-based plants in the United States and imports into the U.S. market by foreign-based companies.

[3]Foreign company entrants since 1972 as a percentage of number of innovative firms in the industry is in parentheses.

[4]Percentage of sales produced overseas by U.S.-based firms is in parentheses.

plants would become an important new approach to controlling pests.

Biological Pesticides

Biological pesticides refer to viruses, parasitic and pathogenic bacteria, and predators. Biological pesticides occur naturally in the environment, have a low probability of adverse health effects, and pose little environmental risk. For example, Hatch (1982) indicates that there is little possibility that insect viruses can affect mammals because mammalian viruses are more specific. In addition, there is virtually no possibility that currently used biological pesticides will migrate outside of their target area because they become active after they are eaten and multiply only in connection with living cells.

Researchers have devoted most of their effort to bacteria and viruses (Plapp, 1993). Bacteria include free-living plant-colonizing bacteria and spores or crystals produced by spores. Both types of bacteria carry a chemical that is toxic to some pests. Free-living plant-colonizing bacteria reproduce and can move between plants. They have an advantage over immobile bacteria in that repeated pesticide applications may not be necessary. However, the EPA has never approved the use of a free-living bacterial pesticide. The EPA rejected a 1985 field permit application by Monsanto because it feared that the bacteria would colonize nontarget plants. Monsanto redesigned its test and met EPA concerns, but eventually chose not to pursue further testing. Krimskey and Wrubel (1993) note that currently no company is conducting research on free-living bacteria.

Current pesticidal bacteria research focuses on spores and crystals. This type of bacterial pesticide has encountered few regulatory roadblocks because it is immobile and occurs naturally in the environment.

There are also other advantages. Hatch (1982) reports that little or no protective equipment is needed, and there is little evidence suggesting that pests develop resistance. Biological pesticides, in general, do not harm beneficial organisms and can be applied up to the time just prior to harvest.

Viruses and bacteria differ significantly from chemical pesticides in that they control rather than eliminate pests, have a delayed impact, and are much more selective. A selective pesticide has a narrow host range because it affects only one or a limited number of pests. Chemical pesticides, in contrast, have a broad host range. They affect many pests, have an immediate impact, and often are toxic to both target and nontarget species.

Many biological pesticides also become effective only after ingestion. Elcar, for example, takes 3 days to kill a young larvae, 4 to 5 days to kill older larvae, and does not affect noneating adults. The incomplete and delayed effect of biological pesticides means that farmers must accept some superficial harm to plants. For example, Hatch (1982) indicates that Elcar, a Heliothis virus, reduces the insect population by about 50 to 60 percent. Hence, biological pesticides are limited to crops in which some leaf damage is not detrimental to the plant (Hatch, 1982).

The EPA established a tier approval system for biological pesticides. Under this program, biological pesticides that pass a short-term test of toxicity to humans and fish and wildlife, pathogenicity, persistence, and replication in mammals can gain waivers against additional human health tests. The EPA also gives regulatory approval priority to biologicals over chemicals and waives some of the 19 tests required of chemical pesticides because they do not apply to biologicals.

There is evidence that biological pesticides have lower regulatory costs. A new chemical pesticide has development costs of $50-$70 million, of which about 25 percent is for regulatory costs. In contrast, Tantillo (1989) reports that one biological pesticide cost only $5 million to develop, including $500,000 for regulatory expenses. She also indicates that a different pesticide required only 6 months to register. In addition, Hatch (1982) indicates that 5 percent of the cost of developing Elcar would have been for regulation had a tier system existed when it came onto the market.

The pace of development of biological pesticides illustrates their lower regulatory costs when compared with chemical pesticides and indicates recent technological advances. Over the 1980-85 period, there were four biological pesticides registered by the EPA. From 1987 to 1992, the EPA registered 13 new biological pesticides. This is particularly noteworthy because it represents about 26 percent of all pesticides registered by the EPA from 1987 to 1992.[26]

Biological pest control systems (pesticide programs in which biological pesticides are the only pest control agents) have been established for citrus, nut, and apple crops. They have also been used as components of integrated pest management in cotton, citrus, rice, nuts, soybeans, vegetables, and deciduous fruit crops. However, biological pesticides have been applied against relatively few economically significant pests and have captured less than 2 percent of the pesticide market.

A lack of farmer awareness may partly account for the low market share of biological pesticides. As noted above, chemical pesticides kill all target pests but a farmer must accept a low level of pest infestation with biological pesticides. Accordingly, it is more difficult to determine when the level of pest infestation has reached a point at which crop damage occurs. In addition, more care is required for properly spraying biological pesticides than for chemical pesticides (Hatch, 1982).

Biological pesticide use may be increased through farmer education and chemical pesticide use restrictions. Most biological pesticides do not have residue tolerances or use restrictions. On the other hand, some chemical pesticides cannot be used for several months prior to crop harvest. Hence, farmers have had to use biological pesticides because restrictions prevent them from applying chemical pesticides. In this vein, Hunter (1990) reports that chemical pesticide spraying restrictions for the 6 months prior to harvest for avocados have encouraged many avocado farmers to use biological pesticides.

Perhaps the biggest reason for the low market share of biological pesticides is their narrow host range. Plapp (1993) indicates that biological pesticides have not been successful as herbicides, which account for about 60 percent of pesticide sales, because target weeds are often replaced by other weeds not affected by the biological pesticide. As a result, of the 13 biological pesticides registered from 1986 to 1992, 5 were insecticides, 6

[26]Recall that for biological pesticides, testing costs are about $500,000 and development costs are about $5 million. For chemical pesticides, regulatory costs are about $15 million and development costs are about $50-70 million. It follows that, since testing and development cost differences are very large now, reductions in regulatory costs would have a small effect on the pace of biological pesticide development if differences in testing and development costs motivate firms to develop biological pesticides.

were fungicides, and 2 were other types. None of the biological pesticides were herbicides.

The narrow host range of biological pesticides does not necessarily suggest that the long-term potential of biological pesticides is limited. Kondo and Maeda (1991) found that viral DNA can be recombined between species, resulting in a wider host range. Hence, wider host ranges may be possible, but wide-range biological pesticides will require additional research.

Genetically Modified Plants

Although seed companies have used genetic breeding to develop plants with unique characteristics for many years, only characteristics particular to the same type of plant can be transferred to a new seed. In addition, the plant breeding process can take up to 12 years before a plant can be commercialized (Gould, 1983). As a result, traditional genetic breeding can be used to develop only a limited number of product characteristics and requires a long development period.

Plant biotechnology facilitates the development of plant qualities not possible through traditional plant breeding and reduces the time required to identify desirable traits. In addition, biotechnology allows researchers to target a single plant characteristic, which decreases the number of unintended changes that may occur with traditional cross-breeding techniques.

Plant biotechnology differs from traditional crossbreeding in that a researcher identifies the desirable genetic information from an outside source and then creates a vector that is used to transfer genetic information to plant cells. Next, the plant is regenerated from a single cell or a collection of cells and the researcher verifies that the plant possesses the desirable characteristics. After obtaining any necessary Federal or State environmental field testing permits or approvals, researchers conduct field tests and obtain traditional field performance data. Such field data are necessary for both regulatory approvals and commercial development.

The cost of genetically modifying plants relative to the cost of developing new chemical pesticides is a prime factor motivating plant biotechnology research into plants with pesticide-like qualities. Recent estimates suggest that genetically modified plants cost about $10 million and require about 6 years to develop, while chemical pesticides cost $50-70 million and take 11 years to develop.[27] In addition, Krimskey and Wrubel (1993) report that it is becoming more costly for firms to develop chemical pesticides that are both harmless to the crops and sufficiently toxic to kill all or most pests.

Growth in the number of environmental release permits indicates the increased pace of technology adoption. From November 1987 to November 1988, USDA's Animal and Plant Health Inspection Service (APHIS) issued 20 environmental release permits. The number of permits increased to 30 for the 12 months preceding November 1989, 50 in 1990, 86 in 1991, and 149 in 1992. By the first half of 1995 over 1,400 field test permits and notifications had been approved at over 3,600 sites throughout the United States.

The research interests of firms using plant biotechnology can be ascertained from environmental release permits. Of the 453 environmental release permits issued from 1987 to July 1993, 139 were for herbicide tolerance, 88 were for insect resistance, 121 were for virus and other pest resistance, and the rest were for product enhancement qualities, such as delayed product spoilage and research needs (Ollinger and Pope, 1995). Herbicide-tolerant plants can withstand applications of a particular type of herbicide and, thus, are designed to encourage farmers to switch pesticide brands (Krimskey and Wrubel, 1993). Pest and insect resistances are designed to replace chemical pesticides if they are targeted at crop markets in which chemical pesticides are used for an identical purpose.

Despite the recent surge of interest in developing genetically modified plants, there may be longrun complications for their use as substitutes for chemical pesticides. Krimskey and Wrubel (1993) note that weeds develop resistance more easily to one herbicide than to several. Hence, herbicide-tolerant plants will accelerate the development of herbicide-tolerant weeds if farmers rely on one or only a few herbicides. Similarly, Krimskey and Wrubel (1993) believe that insects will develop resistances to genetically engineered insect toxins if all plants have this trait. In addition, even if pests do not develop resistances, farmers would still have to monitor their fields and, as with biological pesticides, apply chemical pesticides during periods of high infestation or when there are numerous types of pests.

Pest Control Needs of Farmers of Minor Crops and Pesticide Regulation

Biological pesticides are effective for single-pest infestations in which some leaf damage is acceptable (table 6). Biological pesticides are also effective in combination with chemicals for crops in which some leaf damage is

[27]Based on personal conversations with Sandy Zavolta of the Office of Pesticide Programs at the EPA and officials at Calgene and Mycogen.

Table 6—Likelihood of an effective biological or chemical pesticide being developed for crops that are either permitted or not permitted to have leaf damage and that are attacked by one or more types of pests[1]

			Likelihood of an effective pesticide being developed		
Leaf damage	Number of pests	Type of pesticide	Minor crop market	Medium crop market	Major crop market
Not permissible	Single	Biological	No	No	No
Permissible	Single	Biological	Yes	Yes	Yes
Not permissible	Single	Chemical	No	Maybe	Yes
Permissible	Single	Chemical	No	Maybe	Yes
Not permissible	One major and more than one minor	Biological	No	No	No
Permissible	One major and more than one minor	Biological	Yes[2]	Yes[2]	Yes[2]
Not permissible	One major and more than one minor	Chemical	No	Maybe	Yes
Permissible	One major and more than one minor	Chemical	No	Maybe	Yes
Not permissible	Many	Biological	No	No	No
Permissible	Many	Biological	No	No	No
Not permissible	Many	Chemical	No	Maybe	Yes
Permissible	Many	Chemical	No	Maybe	Yes

[1]This table was created assuming that the current level of technology does not change. Also, it considers the longrun implications of current pesticide regulation. Currently, pesticides exist to meet most farm needs.

[2]Chemical pesticides may be necessary as a supplement.

permissible, and the crops are affected by one major pest and other minor pests. Chemical pesticides, in contrast, are effective in all applications, but will not likely be developed for minor crop markets and may not be developed for medium-sized crop markets because of high testing and development costs.

The tendency of pests to develop resistances to pesticides may further reduce the number of chemical pesticides available for use. Eichers (1980), for example, indicates that insect resistance had caused a drop in sales of DDT, chlordane, and heptachlor before the EPA banned these organochlorine insecticides. Additionally, Eichers (1980) indicates that weed resistance to the herbicide 2,4-D led to the decline in its market share from 32 percent in 1966 to 4 percent in 1976. Similarly, Plapp (1993) reports that 447 species of insects and mites, 100 species of plant pathogens, and 55 species of weeds are known to be resistant in one location to one or more pesticides used for their control. Combining the decline in the number of new chemical pesticide registrations for minor crops with a rise in the number of pests resistant to chemical pesticides suggests a decline in the number of chemical pesticides for minor crops.

Fears of a decline in the number of chemical pesticides for minor crops are not new. Similar fears during the early 1960s led the USDA to establish the Interregional Research Project No. 4 (IR-4) to make it easier to register minor-use pesticides. Currently, IR-4 funds some field tests and works with the EPA to reduce minor-use pesticide field test requirements. Demand for its services has grown recently because the 1988 FIFRA amendment required pesticide manufacturers to reregister all pesticides approved prior to 1984 by 1997. Rather than comply, many manufacturers canceled pesticides that were currently in use. As a result, the number of requests to gather data to support the pesticides about to be canceled was 5,082 minor uses in August 31, 1991. IR-4 identified 1,324 of these requests as those for which the chemical company was willing to register the pesticide use. However, budget limits have prevented IR-4 from meeting all requests (Giannesi and Puffer, 1992).

Some private mechanisms have addressed the needs of farmers of some minor crops. For example, a State-based hops growers' association met to ensure registration of seven pesticides needed for hops production. After gaining the approval of the pesticide company to seek registration, it used funds from members and breweries to register the pesticides. Private sector and IR-4 responses have not met all the needs of farmers of minor crops, however. Giannesi and Puffer (1992), for example, cite six cases in which farmers had no pest-control products after the commonly used chemical pesticide was dropped.

Conclusions

A major impact of increased pesticide regulation is that it causes the number of new chemical pesticides registered by the EPA to drop, with minor-use pesticides affected the most. Minor-use pesticides are used on minor crops and are affected more than major crop pesticides because potential revenues from small crop markets do not support pesticide development and testing costs. Moreover, as testing costs rise, the minimum size market required to support pesticide development costs also rises. To date, regulatory costs appear not to have affected the development of pesticides for major crops, such as corn.

The benefit of regulation is that it encourages firms to develop new chemical pesticides that are less toxic to humans and fish and wildlife. Pesticide companies focused their research on pesticides that degrade rapidly and stopped the development of pesticides likely to persist in the environment. While this finding of lower toxicity to humans and fish and wildlife does not agree with those who suggest that higher testing costs cause firms to develop more toxic pesticides, it does agree with anecdotal evidence related to persistence. This anecdotal evidence suggests that, after the EPA banned DDT and several other chemical pesticides that persist in the environment, regulation has encouraged firms to develop pesticides that are both less toxic and less persistent in the environment.

The decline in new registrations of minor-use chemical pesticides suggests that market opportunities exist for biological pesticides and genetically modified plants. Biological pesticides are environmentally appealing because they occur naturally. Accordingly, they have much lower regulatory-related testing costs, about one-tenth of the $5 million development cost, than chemical pesticides, which cost about $50-70 million to develop, of which about 25 percent is for regulatory costs.

Krimskey and Wrubel (1993) indicate that biological pesticides are effective against specific pests and environmental conditions but are ineffective on crops affected by many types of pests and under diverse environmental conditions. As a result, biological pesticides have only a small share of the total pesticide market. Genetically modified plants with pest-resistant characteristics are also environmentally appealing, but, like biological pesticides, are effective against only specific pests (Krimskey and Wrubel, 1993). The slow pace of chemical pesticide development for minor crops combined with the specificity of biological pesticides and genetically modified plants suggests a decline in the number of pest control alternatives for farmers of minor crops and perhaps a need for public intervention to promote pest management alternatives.

EPA chemical pesticide regulation has also had indirect effects on the numbers and types of pesticide firms. Higher testing costs encouraged some companies to exit the chemical pesticide market and have favored larger foreign-based companies over smaller domestic firms. Although the exit of some companies has reduced the potential for greater innovation, the firms that remain are those better able to exist in a more stringent regulatory environment and, perhaps, more likely to develop less toxic pesticides.

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Appendix A: New Pesticide Registrations

Appendix equation A1 is a reduced-form empirical model of the impact of regulation on new pesticide registrations. It is based on the previous research reported in pages 2 through 4 (Ollinger and Fernandez-Cornejo, 1994b).

$$\ln(N_{i,t}) = \beta_1 + \beta_2\ln(RESEARCH_{i,t}) + \beta INT_{i,t} + \beta_4 RDINT_{i,t} + \beta_5\ln(LSHARE_{i,t}) + \beta_6\ln(LG3SHARE_t) + \beta_7\ln(PESTREG_t) + \beta_8\ln(INDGROW5_t) + \varepsilon_{i,t} \quad \text{(A1)}$$

where $N_{i,t}$ is the number of new pesticide registrations; $RESEARCH_{i,t}$ is pesticide research expenditures; $INT_{i,t}$ is a dummy variable for foreign-based firms that entered the U.S. pesticide market after 1972; $RDINT_{i,t}$ is an interaction term between $INT_{i,t}$ and $RESEARCH_{i,t}$; $LSHARE_{i,t}$ is the lag of firm pesticide market share; $LG3SHARE_{i,t}$ is the lag of firm pesticide growth in market share; $PESTREG_t$ is pesticide regulation; and $INDGROW5_t$ is pesticide industry sales growth. (See variable definitions and expected relationships in appendix table A1.)

New Pesticide Product Market Size, Uses, and Safety

Appendix equation A2 is a reduced-form empirical model of new pesticide product market size. It is based on the previous research reported in pages 2 through 4 (Ollinger, Aspelin, and Shields, 1994).

$$\ln(PSALES_{i,t}) = \beta_9 + \beta_{10}\ln(RESEARCH_{i,t}) + \beta_{11}\ln(LG5SHARE_{i,t}) + \beta_{12}\ln(EIGHTWO_t) + \beta_{13}\ln(AVNUREG_t) + \beta_{14}\ln(AVNU82_t) + \beta_{15}\ln(INDGROW5_t) + \varepsilon_{i,t} \quad \text{(A2)}$$

where $PSALES_{i,t}$ is the new pesticide product market size; $RESEARCH_{i,t}$ is research expenditure; $LG5SHARE_{i,t}$ is the 5-year growth of lagged market share; $INDGROW5_t$ is the 5-year growth in pesticide sales; $EIGHTWO_t$ is a dummy variable defined as one for years after 1981 and zero otherwise; $AVNUREG_t$ is testing costs; and $AVNU82_t$ is an interaction term between $EIGHTWO_t$ and $AVNUREG_t$. The post-1981 period is isolated from the previous period because, with a 10-year average development time, pesticides coming onto market during this period were developed under a stricter regulatory regime that existed after the 1972 amendment to FIFRA. (Variable definitions and expected relationships are in appendix table A2.)

Appendix equation A3 is a reduced-form empirical model of new pesticide crop market uses. It is based on the previous research reported in pages 2 through 4 (Ollinger, Aspelin, and Shields, 1994).

$$PESTUSE_t = \beta_{16} + \beta_{17}AVRDSALE_t + \beta_{18}RESTATE_t + \beta_{19}EIGHTWO_t + \beta_{20}AVNUREG_t + \beta_{21}EIGHTWO \times AVNUREG\varepsilon_t + \varepsilon_{i,t} \quad \text{(A3)}$$

where $PESTUSE_t$ is the average number of crop market uses per new pesticide from 1972 to 1989; $AVRDSALE_t$ is the average research to sales ratio; $RESTATE_t$ is the value of farm real estate; $EIGHTWO_t$ is a dummy variable defined as one for the period after 1981; and $AVNUREG_t$ is testing costs. (Variable definitions and expected relationships are in appendix table A2.)

Appendix equation A4 is a reduced-form empirical model of the proportion of pesticide registrations for major crops relative to registrations for all crop categories (crop type) identified in table 4. It is based on the previous research reported in pages 2 through 4 (Ollinger and Fernandez-Cornejo, 1994b). Note, pesticides can be sold only if they are registered for use on a particular crop (crop use).

$$LARGCROP_t = \beta_{22} + \beta_{23}RDIND_t + \beta_{24}HERF_t + \beta_{25}PESTREG_t + \beta_{26}ACREGRO2_t + \varepsilon_t \quad \text{(A4)}$$

where $LARGCROP_t$ is the ratio of the number of pesticides for large volume crop markets to the number of pesticides developed for all crop markets; $RDIND_t$ is industry pesticide research; $HERF_t$ is the Herfindahl Index; $PESTREG_t$ is regulation; and $ACREGRO2_t$ is the growth in planted agricultural acreage. (Variable definitions and expected relationships are in appendix table A2.)

Appendix equation A5 is a reduced-form empirical model of the effect of regulation on chemical pesticide toxicity to humans and fish and wildlife. It is based on the previous research reported in pages 2 through 4 (Ollinger and Fernandez-Cornejo, 1994b).

$$LESSTOX_t = \beta_{27} + \beta_{28}RDIND_t + \beta_{29}HERF_t + \beta_{30}PESTREG_t + \beta_{31}PRICES_t + \varepsilon_t \quad \text{(A5)}$$

where $LESSTOX_t$ is the proportion of less toxic pesticides to all pesticides; $RDIND_t$ is industry pesticide research expenditures; $HERF_t$ is the Herfindahl Index; $PESTREG_t$ is regulation; and $PRICES_t$ is farm prices. (Variable definitions and expected relationships are in appendix table A2.)

Appendix table A1—Definition of variables for the effect of regulation on new pesticide registrations

Variable	Definition
$N_{i,t}$	The number of new pesticide registrations at the EPA. We follow Thomas (1990) in using new pesticide registrations because it represents the capacity to develop economically useful innovations.
$RESEARCH_{i,t}$	$RESEARCH_{i,t} = \frac{\sum_{j=0}^{n_t} RD_{i,t-j}}{n_t}$ where $RD_{i,t}$ is firm pesticide research expenditures and n_t is the time from discovery to commercialization of a pesticide. Thomas (1990) used a similar definition for pharmaceutical innovations because that industry also had a variable lag structure for product development. Also, Sharp (1986) and National Agricultural Chemicals Association (NACA) data suggest that pesticide research costs are evenly distributed throughout the product development process. Since research expenditures are an investment, a rise in research spending should cause an increase in pesticide registrations.
$INT_{i,t}$	A dummy variable equal to one for foreign-based companies that enter the U.S. market after 1972 and zero otherwise. Since foreign-based companies introduced pesticides into the United States from overseas operations, the entry of foreign-based firms should cause the number of pesticide registrations to rise.
$RDINT_{i,t}$	Interaction term between $INT_{i,t}$ and $RESEARCH_{i,t}$. Foreign-based firms increase their U.S. research spending as the pool of pesticides from overseas operations diminishes. Hence, an increase in U.S. research spending should lead to a decline in the number of pesticide registrations.
$LSHARE_{i,t}$	The lag of market share, which is based on company and industry sales. No prediction can be made of its impact on innovation because it reflects both commodity and proprietary pesticides.
$LG3SHARE_{i,t}$	The lag of the 3-year average of $LSHARE_t/LSHARE_{t-1}$. This definition of growth is employed because our specification is in log form, which does not allow us to use negative numbers. This is a measure of firm success in the marketplace and should positively affect the number of pesticide registrations.
$PESTREG_t$	This regulation variable is defined in a way similar to $RESEARCH_{i,t}$, with staffing level at the Office of Pesticide Programs ($PESTLAB_t$) replacing $RD_{i,t}$. Warren and Chilton (1989) maintain that staffing levels reflect regulatory intensity. We use the average over the product development time because the impact of regulation on the pesticide research process occurs throughout the product development cycle. At any point, a firm may wish to curtail further development because of a revised regulatory environment. For example, the pesticide research opportunity set is limited to only those chemicals that can pass EPA approval. After selecting a promising chemical compound, costs include additional or more rigorous field testing and the possible withdrawal of products that are not able to meet environmental constraints. The next step is for firms to submit their test data to the EPA and then to commercialize the product. Regulation is hypothesized to negatively affect pesticide registrations.
$AVNUREG_t$	This second measure of regulation is defined in a way similar to $RESEARCH_{i,t}$, with the ratio of pesticide research related to environmental expenditures (R_t) to total research expenditures (R_t+NR_t) replacing RD_t. We use this alternative measure of regulation because workers are added in response to greater reporting requirements and thus may understate regulatory impact. Note, NACA reports detailed data on research expenditures for environmental purposes. Regulation is hypothesized to negatively affect pesticide registrations and pesticide crop uses and positively affect new pesticide product market size, the proportion of major crop registrations and the proportion of less toxic pesticides.
$INDGROW5_t$	The 5-year average of S_t/S_{t-1}, in which S_t is current year and S_{t-1} is sales in the previous year. This definition of growth is employed because our specification is in log form, which does not allow us to use negative numbers. Growth should positively affect new pesticide registrations and new pesticide product market size.

Appendix table A2—Definition of variables in equations A2, A3, A4, and A5

Variable	Definition
$PSALES_{i,t}$	New pesticide product market size equals the sum of 3 years of sales for each new pesticide. Three years is assumed because there is a lag between the time a new pesticide is introduced and the time farmers become aware of the qualities of the new pesticide. We assume that a 3-year learning period occurs because sales rankings between 3- and 4-year sales periods did not change for over 95 percent of the new pesticide registrations. $PSALES_{i,j,t} = PSALES1_{i,j,t}+PSALES1_{i,j,t+1}+PSALES1_{i,j,t+2}$ where $PSALES1_{i,j,t}$ is the discounted sales of firm *i*'s *j*th product in year *t*. Subscript *i,j,t+1* refers to the sales of firm *i*'s *j*th product in year *t+1* and *t+2* refers to 2 years after the introduction year. All sales data were deflated to 1972 prices.
$RESEARCH_{i,t}$	See definition in appendix table A1. Since research expenditures are an investment, a rise in research spending should cause an increase in new pesticide product market size.
$LG5SHARE_{i,t}$	The lag of the 5-year average of $LSHARE_t$ /$LSHARE_{t-1}$. This definition of growth is employed because our specification is in log form, which does not allow us to use negative numbers. This is a measure of firm success in the marketplace and should positively affect new pesticide product market size.
$EIGHTWO_t$	One for the period after 1981 and zero otherwise.
$AVNUREG_t$	See definition in appendix table A1. There are two effects of regulation. One is to reduce crop market uses and thus reduce new pesticide product market size. This effect occurs in both the short and long run. The other effect of regulatory costs is to encourage firms to discontinue developing pesticides for minor crops and, thus, raise new pesticide product market size in the long run. $AVNUREG_t$ captures the shortrun effect and the intereaction term (below) captures the longrun effect of regulation on pesticide product market size. Accordingly, it should negatively affect new pesticide product market size and the interaction term positively affect it. Also, $AVNUREG_t$ should negatively affect pesticide crop market uses if regulation causes firms to reduce crop market uses. Regulation is also hypothesized to positively affect the proportion of major crop registrations and the proportion of less toxic pesticides.
$AVNU82_t$	Interaction term between $EIGHTWO_t$ and $AVNUREG_t$. $AVNU82_t$ should positively affect new pesticide product market size and negatively affect pesticide crop market uses.
$INDGROW5_t$	See definition in appendix table A1. Industry pesticide growth should positively affect new pesticide product market size.
$PESTUSES_t$	Ratio of the 4-year moving averages of the number of crop market use registrations to total number of pesticides.
$AVRDSALE_t$	Moving average of the industry research to sales ratio. Defined in a way similar to $RESEARCH_t$. This should positively affect pesticide crop market uses.
$RESTATE_t$	Value of farm real estate, which is used to reflect the health of the farm economy and should positively affect pesticide crop market uses.
$LARGCROP_t$	The ratio of the 4-year moving averages of the number of crop registrations for major field crops to the number of pesticides registered for major and minor field crops, major and minor vegetables, fruits and nuts, and for nursery and other crops. Major field crops include corn, cotton, sorghum, soybean, and wheat. Minor field crops include alfalfa, barley, clover, flax, hops, lentils, mint, oats, peanuts, peas, potatoes, rice, rye, safflower, sunflower, sugarbeets, sugarcane, sweet potatoes, and tobacco. Vegetables include asparagus, beans, broccoli, cabbage, carrots, cauliflower, onions, sweet corn, cucumbers, lettuce, tomatoes, and 35 other vegetables having less than 100,000 acres planted. Fruits and nuts include apples, grapes, nectarines, peaches, pears, plums/prunes, citrus, strawberries, almonds, pecans, walnuts, and 52 other fruits and nuts having less than 100,000 acres. Nursery and other crops include greenhouse crops, grass and turf crops, conifers, five other nursery uses, forage and pasture, storage, forestry, and five other noncrop and non-nursery uses.
$RDIND_t$	Industry research, which is defined in a way similar to firm research $RESEARCH_{i,t}$. This should negatively affect pesticide toxicity and positively influence the proportion of pesticide registrations for major crops.
$HERF_t$	The Herfindahl Index, which is defined as the sum of the squares of company market shares and should positively influence the proportion of pesticide registrations for major crops and pesticide toxicity.
$ACREGRO2_t$	The 2-year moving average of the ratio of current year planted acreage to previous year planted acreage.

Continued—

Appendix table A2—Definition of variables in equations A2, A3, A4, and A5—continued

Variable	Definition
$LESSTOX_t$	The ratio of the 4-year moving averages of the number of less toxic pesticides registered to all pesticides registered. We used two definitions. Under the first definition, a pesticide is "more toxic" if it has a Class 1 acute toxicity rating, is chronically toxic, or is toxic to fish or wildlife. This definition includes all types of pesticide toxicity considered by the EPA. The second definition of a "more toxic" pesticide includes only those pesticides with chronic and fish/wildlife toxicity. We define "more toxic" in this way because the 1972 FIFRA amendment focused on chronic health effects and the toxicity of pesticides to fish and wildlife.
$PRICES_t$	Deflated agricultural prices.

Industry Composition

The following reduced-form empirical model was used to examine the effect of regulation and several other variables on the number of innovative chemical pesticide companies. This model is based on the previous research reported in pages 2 through 4 (Ollinger and Fernandez-Cornejo, 1994a).

$$F_t = \beta_{32} + \beta_{33}LRDSALE_t + \beta_{34}ALLREG_t + \beta_{35}LPOLLUTE_t + \beta_{36}LSTAGE_t + \beta_{37}LRESTATE_t + \varepsilon_t \qquad (A6)$$

where Ft is the number of chemical pesticide companies; $LRDSALE_t$ is the research to sales ratio; $ALLREG_t$ is pesticide regulation; $POLLUTE_t$ is pollution compliance costs; $LSTAGE_t$ is the stage of the industry growth cycle; and $LRESTATE_t$ is farm sector demand. (See variable definitions and expected relationships in appendix table A3.)

We use a reduced-form model (appendix equation A7) to examine the causes of the growth of the U.S. market share of foreign-based firms ($FORSHARE_t$). This model is based on the previous research reported in pages 2 through 4 (Ollinger and Fernandez-Cornejo, 1994a).

$$FORSHARE_t = \beta_{38} + \beta_{39}LRDSALE_t + \beta_{40}ALLREG_t + \beta_{41}POLLUTE_t + \beta_{42}LSTAGE_t + \beta_{43}LRESTATE_t + \varepsilon_t. \qquad (A7)$$

(See variable definitions and expected relationships in appendix table A3.)

The following is an empirical model of merger choice ($MERGE_{i,t}$). It is based on the previous research reported in pages 2 through 4 (Ollinger and Fernandez-Cornejo, 1994a).

$$MERGE_{i,t} = \beta_{44} + \beta_{45}PRICCOST_{i,t} + \beta_{46}EPACOST_{i,t} + \beta_{47}WRLDSALE_{i,t} + \beta_{48}USSHARE_{i,t} + \varepsilon_{i,t} \qquad (A8)$$

where $PRICCOST_{i,t}$ is profitability; $EPACOST_{i,t}$ is firm regulatory costs; $WRLDSALE_{i,t}$ is world pesticide sales; and $USSHARE_{i,t}$ is U.S. market share. $MERGE_{i,t}$ equals 2 if the firm is an acquiring company, 1 if the firm makes no transaction, or 0 if the firm is being acquired. (See variable definitions and expected relationships in appendix table A3.)

Appendix B: Data

Data for the regression analyses came from several sources. The analysis of pesticide innovation contains pesticide registrations from all firms that introduced at least one new pesticide, that were ranked in the top 20 pesticide companies at least once, and for whom research and development data were available over the 1972-89 period. We used Aspelin and Bishop's (1991) report to identify new pesticide registrations.

We obtained firm research and development expenditures from *The Survey of Industrial Research and Development* at the Census Bureau. The Census Bureau conducts the survey for the National Science Foundation and asks questions on firm-level research for each year from 1972 to 1989 and research expenditures for specific categories, such as industry, State, and environmental, for all years except 1978, 1980, 1982, 1984, 1986, and 1988. We define all research in the category on agricultural chemical research as expenditures on pesticide research because the firms in the sample did not produce fertilizers.

All firms did not report at the same level of detail because reporting research expenditures by category is voluntary. One firm did not report any agricultural chemical research expenditures and was dropped. Several other companies failed to report agricultural

Appendix table A3—Variable definitions of the effect of regulation on industry composition

Variable	Definition
F_t	Number of companies that were ranked in the top 20 in sales in at least 1 year over the 1972-89 period and all firms that introduced pesticides and conducted agricultural research during the 1972-89 period.
$FORSHARE_t$	Sum of U.S. market shares held by foreign-based companies. Foreign-based companies are those firms with central offices outside of the United States.
$LRDSALE_t$	Lagged industry research to sales ratio. Higher research costs should cause firms to abandon the U.S. market and favor large firms. Hence, it should negatively influence the number of firms and positively affect foreign-based company market share.
$ALLREG_t$	Lag of 4-year moving average of the ratio of expenditures for environmental and health testing purposes to total research expenditures. Higher testing costs should raise costs and thus negatively affect the number of firms and positively influence the market share held by foreign-based companies.
$POLLUTE_t$	Lag of capital expenditures for pollution abatement equipment to industry sales.
$LSTAGE_t$	Lag of the capital expenditures to sales ratio. A proxy for the stage of industry growth that should positively influence the number of firms and negatively affect foreign-based firm market share.
$LRESTATE_t$	Lagged real estate values. A measure of the health of the farm economy. It should positively affect the number of firms and negatively influence foreign-based company market share.
$MERGE_{i,t}$	Two for an acquiring company *i* in year *t*, one for status quo firms *i* in year *t*, and zero for a company *i* that merged into another firm in year *t*. Note, that we define *t* as the years in which at least one merger of pesticide companies occurred. Also, we define status quo companies as firms that made no acquisitions throughout the study period. We include acquired and acquiring companies only in the years in which they make a transaction. We include status quo companies every year that a transaction takes place.
$PRICCOST_{i,t}$	Price cost margins defined as $((VALADD_{i,t}-COST_{i,t})/VALADD_{i,t})-(RD_{i,t}/SALES_{i,t})$ where $VALADD_{i,t}$ equals the total value of shipments plus the end of year inventory minus the beginning of the year inventory minus the cost of resales; $COST_{i,t}$ includes building rental payments, fuels, materials, purchased communication, purchased electricity, contract work, machinery depreciation, salaries and wages, plus beginning of period materials and work in process minus end of year materials and work in process; $RD_{i,t}$ equals research and development expenditures; and, $SALES_{i,t}$ is company sales. Higher profitability should encourage firms to expand. Thus, a positive relationship is expected.
$EPACOST_t$	Fines levied by the EPA and lost sales of pesticides banned by the EPA. $$EPACOST_{i,t} = \frac{\sum_{z=72}^{z=t} EPAFINE_{i,z} + \sum_{z=72}^{z=t} LOSTSALE_{i,z}}{SALES_{i,t}}$$ where $EPACOST_{i,t}$ is regulatory costs for firm *i* in year *t*; $EPAFINE_{i,z}$ is EPA fines levied on firm *i* in year *z*; $LOSTSALE_{i,z,j}$ is sales lost by company *i* in the year *z* that product *j* was banned; and $SALES_{i,t}$ is defined as sales by firm *i* in year *t*. For all companies that merged, year *t* is their merger year; for companies that do not merge, it is any year in which at least one merger occurs. A firm's inability to avoid environmental penalties and lost sales should encourage a firm to exit an industry. Thus, penalties and lost sales due to regulatory violations should negatively affect merger choice.
$WRLDSALE_{i,t}$	World sales. Used to control for firm size.
$USSHARE_{i,t}$	U.S. market share. Used to show the relationship between acquiring firms and U.S. market share.

expenditures during reporting years. Supplemental data for 1989 and all of the data for 1991 came from Kline and Company reports. For years in which firms provided no voluntary data, companies often provided detailed research data in their annual reports, SEC filings, or in EPA estimates. Accordingly, if annual reports, SEC filings, and EPA data were more detailed than Census Bureau data, we used that information. Employing this methodology, we obtained a time series of data from 1972-91, excluding some firms in 1978, 1980, 1982, 1984, 1986, 1988, and 1990. We estimated research expenditures during these years from research expenditures in the surrounding years and firm research.

In addition to the research data for the 1972-91 period, we also needed estimates of pesticide research spending from 1965 to 1972 because of the lag between research spending and pesticide registration in the pesticide research term. Our estimates are based on firm agricultural research spending in 1972, firm research spending over the 1965-72 period, and pesticide industry research. Combining these data with our other data yielded a data set that covered the 1965-91 period. All values were deflated by the Gross National Product price deflator.

We used both the *Product File* at the Census and Kline and Company data to determine market share. The *Product File* contains total value of production, values for single products defined at the five-digit Standard Industrial Classification (SIC) level, and miscellaneous production data at the establishment level. We used the value of shipments to determine domestic production of pesticides. These are listed under SIC 28694 and all five numbers under SIC 2879. Since domestic production includes pesticides for exports for domestic producers and nothing for foreign producers, we also considered Kline Company data, which contain estimates of domestic and foreign sales over the 1974-91 period. If the reported value of Census shipments was greater than 120 percent of the Kline estimates or less than 80 percent of the Kline estimates, we assumed the company was either an exporter or importer and used Kline estimates. If values of Census production fell within these limits, then the firm was assumed to be producing only for domestic consumption and Census data were used. After making these adjustments, we computed estimated industry sales and compared them to values reported by NACA. The estimates are consistent with the NACA data.

We used labor employment at the EPA Office of Pesticide Programs for computing $PESTREG_t$. Data came from Arnold Aspelin at the EPA. Industry testing costs, which were required for $AVNUREG_t$, came from NACA. These costs were assumed to include all environmental testing, mammalian toxicity studies, and EPA registration costs. Non-testing costs were assumed to be search, synthesis, field testing, and process development costs.

We obtained industry sales and industry average product development periods from NACA surveys. All data were deflated by 1972 prices. We used the sales data in computing industry sales growth and the average product development time in the research term.

We used *Doanes Major Crop Study* (1972-91) reports to determine new pesticide sales. Since 3 years of new pesticide sales data were required, the sample of new pesticide registrations spans the 1972-89 period. The year of introduction was assumed to be the first year in which the Doanes data indicate that sales existed. All sales data were deflated to 1972 prices by the GNP deflator. Note, this sample includes only the years in which firms introduced new pesticides.

Data on pesticide crop market uses came from the *Pest Bank—November 1991*, which is provided through the National Pesticide Retrieval System. Industry research and development came from NACA surveys. Industry profits came from Census files. Farm income, farm prices, and planted farm acreage came from *Agricultural Statistics*. All financial values were deflated by the GNP price deflator. We used the *Farm Chemicals Handbook*, CPCR, and EXTOXNET to determine pesticide toxicity to humans and fish and wildlife. Toxicity to humans and fish and wildlife and crop market classifications are given in table 2.

Kline and Company industry survey data were used to determine whether a firm was ranked in the top 20 in sales. To determine the other companies in the industry, we used agricultural research data from the Survey of Research and Development at the Census Bureau and Aspelin and Bishop (1991) to determine companies that registered new pesticides.

We used Eichers (1980) to determine if a company existed in 1967. If not, we assumed the entry year to be either the first year in which the company reported research and development expenditures at the Census Bureau, the first year in which it registered a new product as reported in Aspelin and Bishop (1991), or the first year in which it appeared in Kline and Company data (1974-89), whichever came first. We assumed exit years to be the year in which a company sold its agricultural chemicals business or the last year in which a company reported research and development expenditures to the Census Bureau.

We based company size on a sales ranking of companies according to 1972 world sales. Companies that entered the industry after 1972 had no sales in 1972 and were thus identified as small companies. Sales rankings and worldwide sales for ($WRLDSALE_{i,t}$) comes from SRI International and Kline and Company.

We used the *Product File* at the Census and Kline and Company data to determine foreign-based company market share, firm sales, and U.S. market share. Industry sales and research expenditures for the 1971-89 period and research costs for small and large companies for the 1977-89 period came from an annual industry survey conducted by NACA from 1971 to 1989 and Kline and Company data. Environmental and health test costs also came from the NACA survey.

Capital expenditures for computing $POLLUTE_t$ came from the Census Bureau publication entitled *Pollution Abatement Costs and Expenditures - Current Industrial Reports.* Industry capital expenditures for the computation of $LSTAGE_t$ came from the Census Bureau files of industry capital expenditures. Lagged real estate values ($LRESTATE_t$) came from *Agricultural Statistics.* Merger data came from Kline and Company and various *Wall Street Journal Indexes.*

We used the Longitudinal Research Database, the Survey of Research and Development, and U.S. sales data from SRI International and Kline and Company to compute firm price cost margin adjusted for research intensity. The Longitudinal Research Database contains over 100 factory-specific responses to survey questions from 55,000 to 70,000 establishments for each year from 1972 to 1988. The sample size and reporting variables vary according to the survey mandate.

The cost of fines levied against pesticide companies came from various annual reports. A complete listing of banned products came from Dr. Kent Smith at the Pesticide Assessment Laboratory of the Agricultural Research Service of USDA. We defined lost sales due to regulatory action as the sales of a banned product in its last year prior to its banishment.

Appendix C: Estimation

We used a two-stage quasi-likelihood (QL) method to estimate appendix equation A1. It was necessary to create an instrumental variable for firm pesticide research ($RESEARCH_{i,t}$), because new pesticide registrations can also affect pesticide research expenditures in future years. We purged this dependence of pesticide research on new pesticide registrations by creating $RESEARCH_{i,t}$, which is the predicted value of firm pesticide research expenditures. We obtained the predicted values of this research variable by regressing it on overall firm research and all of the exogenous variables of appendix equation 1. We define overall firm research in a way similar to $RESEARCH_{i,t}$ in appendix table A1. Research expenditures for the entire firm came from the *Survey of Research* at the Census Bureau, Kline and Company data, and *Moody's Industrial Manual.*

New pesticide registrations approximate a Poisson distribution, with most firms in most years introducing no new pesticides. One approach may be to use a Poisson regression, but such a specification requires that the mean be equal to the variance. Interfirm differences in innovative efficiency cause the variance to grow faster than the mean, resulting in over- (under)-dispersion (Gourieroux, Monfort, and Trongon, 1984).

McCullagh and Nelder (1983) demonstrated that the use of QL techniques overcomes problems of over- (under)-dispersion by providing added flexibility to a Poisson regression. Rather than strictly defining a statistical relationship, this method allows the mean to be proportional only to the variance. Moreover, the unknown distribution is specified to be of the linear exponential family, a general class of distributions. See Thomas (1990) for a more complete discussion.

QL estimates can be obtained with the use of nonlinear weighted least squares with the variance term V(u) as a weight. The dispersion parameter (σ^2_{est}) is estimated with appendix equation C1. A value of one indicates an absence of over- (under)-dispersion.

$$\sigma^2_{est} = \sum_k \frac{(y-u)^2}{V(u)} / (k-p). \qquad \text{(C1)}$$

Inference about individual parameters b was based on the asymptotic standard errors and t-statistics reported in the weighted least squares outputs of statistical packages. Inference for multiple parameters is based on the QL function, l(u;y). For a Poisson distribution, this QL function is specified as

$$l(u;y) = y \log(u) - u. \qquad \text{(C2)}$$

The QL function and the dispersion parameter in equation 6 are then used to compute χ^2

$$2 \Delta QLF = 2\Big(\sum_k 1 \,(U(b_{max};y) - \sum_k 1 \,(U(b_{rest};y)) \sim \sigma^2_{est}\, \chi^2_{p-q} \qquad \text{(C3)}$$

Note, b_{rest} are restricted parameter estimates and b_{max} are unrestricted estimates.

We also used a two-stage QL method to estimate appendix equation A2. As with new pesticide registrations, it was necessary to create an instrumental variable for firm pesticide research ($RESEARCH_{i,t}$), because market size for new pesticides can affect pesticide research expenditures in future years through the lag term. The instruments included total firm research spending and all exogenous variables of appendix equation A2.

The market size for new pesticides approximates a gamma distribution, with most new pesticides in most years realizing low sales but some pesticides in some years having high sales levels. One could use a gamma regression, but that requires that the mean be equal to twice the variance. As indicated earlier, interfirm differences in new pesticide product market success cause the variance to grow faster than the mean, resulting in over- (under)-dispersion (Gourieroux, Monfort, and Trongon, 1984). Hence, we used a QL regression technique.

We also used a two-stage estimation procedure to estimate appendix equation A3 because pesticide crop market uses may affect research through the lag of research. As instruments, we used 3-year farm income growth, the capital to sales ratio, farm real estate, and all exogenous variables of appendix equation A3. Next, we used Ordinary Least Squares (OLS) to determine whether autocorrelation was present in the model. We determined that it was; thus, we adjusted for autocorrelation. As a check, we used a "one-limit" tobit model because pesticide crop market uses are bounded from below by one (Maddala, 1983). We used the OLS adjusted for autocorrelation model because the limit is not binding.

The inter-relatedness of the impact of an increase in regulation on innovation (appendix equation A1), pesticide crop market size (appendix equation A4), and pesticide toxicity to humans and fish and wildlife (appendix equation A5) makes the use of a Seemingly Unrelated Regression (SUR) econometric method appropriate. Appendix equation A2 covers the 1972-91 period and calls for firm-level data; while appendix equations A4 and A5 cover the 1972-89 period and make use of industry data. Hence, only appendix equations A4 and A5 are included in the SUR system.

We used a two-stage SUR method to estimate appendix equations A4 and A5. First, we created an instrumental variable ($RDIND_t$) for industry pesticide research ($RDIND_t$). We used value-added and all the exogenous variables of appendix equations A2 and A3 as instruments. Value added came from Bureau of the Census files. Next, we used OLS to determine whether autocorrelation was present. We determined that it was not. We then estimated appendix equations A4 and A5 with a "two-limit" tobit regression, because both equations are bounded between zero and one (Maddala, 1983). Results were similar to those of the OLS because the limits were not binding. Satisfied that neither autocorrelation nor the theoretical bounds would bias results, we used the instrumental variable for industry pesticide research and the other variables of appendix equations A4 and A5 in a SUR econometric model. We made no adjustments for autocorrelation. The Durbin-Watson statistics ranged from 1.87 to 2.08.

We estimated appendix equations A6 and A7 separately because Zellner (1962) and Dwivedi and Srivastava (1978) found that SUR techniques are not necessary for the case in which regressors are the same across all equations and there are no theoretical restrictions for the regression coefficients. They show that the matrix is the same and single-equation estimation yields the same results as SUR methods. Additionally, we did not include appendix equation A3 in a system because it covers a different time period than the other two equations and is based on firm-level rather than industry data.

We used two-stage least squares to estimate appendix equations A6 and A7. It was necessary to purge the research term of its dependence on regulation and other factors because research spending is affected by pesticide product regulation. We employed all exogenous variables and new pesticide product sales as a fraction of industry sales as instruments. For the small and large firm research-to-sales ratios, we also used the industry research to sales ratio as an instrument. Results were also adjusted for autocorrelation.

We used OLS adjusted for autocorrelation for the regressions of the factors influencing the number of firms (appendix equation A6) and the market share of foreign-based companies (appendix equation A7). For the foreign-based-company market share model, we checked our results with a "two-limit" tobit because the regression is bounded between zero and one (Maddala, 1983). Results were similar to that of the OLS adjusted for autocorrelation model because the limits are not binding.

We used a multinomial logit econometric technique for the merger choice model because there were three types of firms in the industry: companies that buy another firm, firms that are bought, and companies that are involved in no transactions (appendix equation A8). We include firms that make no transactions in every year of the study period and acquiring and acquired companies only in the year in which they are involved in a transaction.

U.S. Department of Agriculture
Economic Research Service

SUMMARY OF REPORT #AER-717

Trends in Use of Fertilizers And Pesticides

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Pesticides and fertilizers contribute to increased productivity in agriculture, but their use is also associated with potential human health, wildlife, and environmental risks. Pesticides used on major crops more than doubled during 1964-82 (from 233 to 612 million pounds of active ingredients).

Total expenditures for agricultural chemicals showed a continuous upward trend before peaking in 1982. During this time, fertilizers and pesticides were applied to more acres, and application rates increased. Since 1982, total agricultural chemical usage has varied mainly with changes in planted acreage, government set-aside requirements, and levels of pest infestation.

Pesticide and Fertilizer Use and Trends in U.S. Agriculture, a new report from USDA's Economic Research Service, provides information to facilitate policy and regulations related to agrichemicals, and to identify measures that can reduce agrichemical use on corn. The report describes the trend in pesticide and fertilizer use in selected crops from 1964 to 1992. Information is reported for four major pesticide types (herbicides, insecticides, fungicides, and other pesticides). Fertilizers are reported by plant nutrient (nitrogen, phosphate, and potash).

Because recent U.S. Department of Agriculture (USDA) chemical use surveys have not covered all agricultural use, the pesticide use trend is limited to those crops with consistent coverage over time. The included crops (corn, cotton, soybeans, wheat, rice, grain sorghum, peanuts, fall potatoes, other vegetables, citrus, and apples) occupied about 250 million acres (73 percent) of U.S. cropland in the early 1990's and accounted for about 80 percent of total pesticide use in U.S. agriculture during the 1960's. The fertilizer use trend is reported annually for all purposes (agriculture and nonagriculture) and for four crops (corn, cotton, soybeans, and wheat).

Highlights of the report:

- During the 1960's, agricultural pesticide use was dominated by insecticides, accounting for half of all pesticides used. Since 1976, insecticide use has declined, mainly in cotton production, and has accounted for 10 percent of total agricultural pesticide use in recent years.
- During 1964-82, agricultural herbicide use increased more than eightfold, accounting for much of the increase in total pesticide use during the period. Herbicide use accounted for about 70 percent of agricultural pesticide use in recent years. Fungicides and other pesticides (soil fumigants, growth regulators, and harvest aids) accounted for about one-fifth of total pesticides in recent years.

To Order This Report...

The information presented here is excerpted from ***Pesticide and Fertilizer Use and Trends in U.S. Agriculture,*** AER-717, by Biing-Hwan Lin, Merritt Padgitt, Len Bull, Herman Delvo, David Shank, and Harold Taylor. The cost is $9.00.

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